1

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GCA/LSY/91S-6

ESTIMATE-AT-COMPLETION RESEARCH - A REVIEW AND EVALUATION

THESIS

JOHN W. McKINNEY
GS-12, USAF

AFIT/GCA/LSY/91S-6

The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

AFIT/GCA/LSY/91S-6

ESTIMATE-AT-COMPLETION RESEARCH - A REVIEW AND EVALUATION

THESIS

Presented to the Faculty of the School
of Systems and Logistics of the
Air Force Institute of Technology
Air University
In Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Systems Management

John W. McKinney, B.S.
GS-12, USAF

September 1991

Preface

The purpose of this study was to review the literature concerning Estimate-at-Completion (EAC) models. This thesis identifies the studies and their sources, provides a categorization and summary of the studies, and analyzes the studies for strengths and weaknesses in relation to the results. The research establishes a foundation or starting point from which future research can expand upon.

I would like to thank my faculty advisor, Major David Christensen, for his advice, patience, and assistance. Thanks also goes to Mr. Richard Antolini for being a reader for this thesis. I would like to thank my wife, Beverly, and children, Jason, Amanda, and Jennifer for their motivation and patience during this difficult time.

Table of Contents

Page

Preface ii

List of Tables v

Abstract vi

I. Introduction 1

General Issue 1
Research Goals 4
First Objective: Identify and Collect . . 6
Second Objective: Categorize and Summarize 6
Third Objective: Analysis of Research . . 6
Fourth Objective: Study Results 7
Limitation of Study 8

II. Description of EAC Models, Studies, and Other Sources 9

Forecasting 11
Past Performance Factors 14
Holeman Model (1975:3) 16
Lollar Model (1980:10) 18
Totaro Model (1987:19) 19
Blythe 1982 Study (1982:14) 19
Blythe 1984 Study (1984:15) 21
Cryer and Balthazer Study (1986:17) 22
Wallender Study (1986:18) 23
Price Study (1985:16) 24
Reidel and Chance Study (1989:20) 25
Covach (NAVSEA) Study (1981:11) 28
Land and Preston Study (1980:9) 32
Bright and Howard Study (1981:12) 34
Regression Analysis 36
Karsch Study (1974:2) 38
Heydinger (SAMSO) Study (1977:7) 39
Other Techniques 41
El-Sabban Study(1973:1) 41
Time Series Analysis 43
Busse Model (1977:5) 44
Chacko Study (1981:13) 45
Weida Model (1977:8) 45
Summary 47

Page

III. Analysis of Research Studies 48

Evaluation Criteria 48
El-Sabban Model (1). 53
Karsch Model 1974 (2). 54
Holeman Model (3). 55
Busse Model (5). 56
Heydinger (SAMSO) Study (7). 56
Wieda Model (8). 58
Lollar Model (10). 58
Chacko Approach (13) 59
Blythe 1984 Study (15) 59
Totaro Model (19). 60
Model/Approach Summary. 61
Analysis of Comparison Studies. 61
Karsch (1976) Study (4). 62
Hayes Study (6). 62
Land and Preston Study (9) 63
Covach (NAVSEA) Study (11) 64
Bright and Howard Study (12) 65
Blythe (1982) Study (14) 66
Price Study (16) 67
Wallender Paper (18) 68
Balthazer and Cryer Study (17) 68
Reidel and Chance Study (20) 69
Summary 71

IV. Conclusions and Recommendations. 72

First Objective: Identify and Collection . . 72
Second Objective: Categorization and
Summarization 73
Third Objective: Analysis of Studies 74
Fourth Objective: Study Results. 76
Summary 78
Recommendations for Future Studies. 79

Appendix A: Explanation of Cost/Schedule Control
Systems Criteria (C/SCSC) 81

Appendix B: Formulas. 87

Appendix C: EAC Formulas. 89

Bibliography. 96

Vita. 101

List of Tables

Table Page

1. Summary of EAC Studies and Models 12

2. Summary of Reidel and Chance Study. 27

3. Analysis of EAC Models and Studies. 50

AFIT/GCA/LSY/91S-6

Abstract

This research derives from the Performance Measurement discipline and consists of a comprehensive analysis of Estimate-At-Completion (EAC) studies published since 1973. The EAC studies consisted of models, comparison studies, and computer analysis programs. The studies were located through the Defense Technical Information Center (DTIC), the Cost Library at Wright-Patterson Air Force Base, OH, and professional periodicals or contracted research.

Each study was categorized by formula type and described in terms of methodology and conclusions. Each study was evaluated based on clarity, documentation, methodology, and source. The description and evaluation of the studies are summarized in two tables.

After reviewing the studies some areas were found to be weak. The AFSC formula that uses weighted percentages of .2 SPI and .8 CPI, is not supported by a critical review of the literature. In the area of comparison studies, different past performance factor formulas have been compared with respect to different percent completion points, type of contract, and type of product. A summary of the results are provided in Chapter II. Little work has been done comparing regression formulas to past performance factor formulas. An important outcome of this research identified the scarcity

of formal EAC theory or relevant research concerning the underlying causes of "Why" certain EAC formulas are better predictors of performance.

ESTIMATE-AT-COMPLETION RESEARCH -
A REVIEW AND EVALUATION

I. Introduction

General Issue

The purchase of weapons used by the military to defend our nation and aid other countries is a major function of the Department of Defense (DOD). A dynamic and critical part of this acquisition process is estimating the cost of these weapon systems. In a 1990 keynote speech given to a Cost Analysis Symposium by the former Under Secretary of Defense (Acquisition), John Betti, the function of cost estimating was defined.

> Your products are cost estimates. Your customers are the people who use those estimates in the decision making process. . . . . The cost estimates are critical ingredients in deciding among competing alternatives and in establishing fundamental priorities. They are equally important in monitoring the execution of approved programs.
>
> (4:3)

DOD cost estimates have made the evening news, generated newspaper and magazine articles and shortened civilian and military careers such as in the Navy A-12 program (35:30-31). Managing government programs is not an easy road. Early detection of problems can save a program from becoming current news.

In order for a program manager to successfully accomplish a project, tradeoffs between schedule, contract progress (performance) and cost must be managed (34:12). Robert Tiong stated ""on time", "within budget" and "according to specifications" should be the basic objectives of the program control system for any major project" (44:32). When costs start to increase it is a good indicator that the program and the internal process are in trouble (4:4). Monitoring the program cost through the cost estimating process can provide early warning to the program manager of potential problems. Early detection enables the program manager to address the problems and manage cost, schedule and performance before they become nonrecoverable.

An example of the importance of EAC formulas is the Navy A-12 program. The A-12 program was a medium stealth bomber that was designed to replace the A-6 Intruder. Concept formulation started in 1984 with the FSD contract awarded to McDonald Douglas and General Dynamics in 1988. This program was terminated for default on Jan. 7,1991 after an investment of $3.1 Billion (35:30). A report for the Secretary of the Navy concerning the A-12 program indicated the program analyst provided cost estimates generated by formulas which forecasted a sizeable cost growth on the contract. According to the report, the program manager elected not to use the estimates, but developed a cost estimate that was lower than the estimate of the program analyst. An independent review of the contract produced an

estimate that was considerably higher than the low estimate briefed by the program manager to the Major Aircraft Review (MAR) committee (3:12-13). The independent estimate supported the cost analyst's position. This was only a part of the problem, but the final result made headlines with the termination of the A-12 program and resignation of high-ranking civilian and DOD personnel.

The Gramm-Rudman-Hollings Act, ending of the Cold War, internal economic problems in the United States, and public opinion factors are driving Congress to balance the Federal budget. The budget of the Department of Defense (DOD) has declined for the last six years (4:3). The DOD, program managers and financial managers are convinced the budget cuts are the beginning of a new era. John Betti, in his speech to the DOD Cost Analysis Symposium, enforced this belief.

> The costs are very important because the competition for the taxpayers' dollars is becoming ever more fierce. We all know that defense budgets are getting tighter. FY91 budget will likely mark the sixth straight year of decline in real dollars for the DOD. . . . . There is little reason to believe that we should expect more liberal defense spending in the foreseeable future.
>
> (4:3)

In order to meet the ever tightening budgets, the DOD needs reliable and sometimes frequent cost estimates from which to prepare and defend its budgets and programs. This is not only true at the Congressional level but also within the DOD itself, at the Service level (Air Force, Navy, etc.)

and within each Service. The bottom line with most reviews is "How much will it cost?" The estimate of the forecasted final contract cost is termed an Estimate-at-Completion (EAC) (22:113).

The decreasing dollars and increasing problems from advanced technology (schedule delays, rework) will make the job of program manager even tougher. General Nauseef reiterated this idea in a keynote speech to the 1990 Cost/Schedule Control System Criteria National Workshop.

> At the same time, the acquisition of major systems is more complicated. Cutbacks are impacting program management programs with cost and schedule problems receiving more visibility . . . . . As the budget gets smaller cost and schedule perturbations get bigger and receive more attention. Ever programs with good cost performance will be caught in the budget changes.
>
> (36:25)

Cost estimating is now in the spotlight and the importance of cost estimating to a program, the DOD and program managers, is at a critical level.

Research Goals

The manager (Government and Contractor) of a program relies upon the financial community to provide an Estimate-at-Completion (EAC). The estimate can be very detailed and take months to finish or it can be produced in a short amount of time by using formulas. The quick turn around time the DOD expects for information and the internal time constraints in the program office make the use of formulas

very convenient. This is the area of focus for this research -- Estimate-at-Completion formulas.

A review of the available studies over the last 20 years produced some general observations about the EAC area. The trend in recent EAC studies has been a comparative type of research. This type of research uses a small sample of EAC formulas, collects specific data with respect to product or acquisition phase (Research & Development, Production), and statistically or mathematically evaluates the formulas in order to pick the "best" predicting formula. There seems to be no basic theory developed upon which the studies are based. Some of the earlier studies dealing with the weighting of indices (Schedule and Cost) showed conflicting results using the same data bases.

Developmental model research has been done but most of the models are poorly documented and lack validation. In addition there has been little follow-on work to expand or justify the formulas. It is hard to do development or follow-on research when you do not know what has already been accomplished. After the research has been accomplished, distribution to the users in the EAC field appears to be limited and few studies are published in periodicals or professional journals. There appears to be many studies that have been accomplished, read by one person, then placed in a library never to be seen again.

A theoretical base from which to work is missing in the EAC area. The studies are like individual building blocks

waiting to be joined into a foundation for future expansion. Unless the base is defined there is no starting point for progressive expansion of EAC research. This can result in repetitive and poorly designed research work that can stagnate advancement in the EAC area.

This research has four objectives which are presented below.

First Objective: Identify and Collect.

In order to know what has been accomplished, Estimate-at-Completion studies and sources of EAC formulas must be identified and collected. This research will identify and collect available EAC studies and sources.

Second Objective: Categorize and Summarize.

After collecting the research sources, they will be categorized and summarized by formula type, time frame, source type (service doing formula), and the database used in the research. This will show what study trends and areas of concentration the research has focused upon.

Third Objective: Analysis of Research.

Once summarized, the studies will be analyzed for strengths and weaknesses. Methodology, documentation, data sampling, clarity, and logic behind the study will be reviewed. The analysis should provide a measurement of the confidence that can be applied to the conclusions of the research.

Fourth Objective: Study Results.

The final objective is to evaluate the conclusions of the research based upon the merits of the studies. This will establish a starting point from which future research can build. Establishing the historical base would allow for a more scientific approach to EAC research rather than "shooting in the dark".

As this review looks at different studies, approaches, computer analysis programs, classroom instruction, and models there is one common thread that weaves throughout the studies. The formulas incorporate Cost/Schedule Control System Criteria (C/SCSC) data element terminology.

Most major defense contracts are required to submit Cost Performance Reports (CPR) or Cost Schedule Status Reports (C/SSR). For contractors submitting CPRs, their system must pass an evaluation based on the DOD Cost/Schedule Control Systems Criteria (C/SCSC). One of the goals of C/SCSC is to provide confidence that the data provided are accurate and reliable (16:1-1).The data element nomenclature is unique to the C/SCSC area. In order to understand the terms and assumptions used throughout this study, a brief explanation of C/SCSC, related performance reports,and terms are provided in Appendix A with the mathematical relationships presented in Appendix B.

Limitation of Study

The research sources reviewed represent the majority of the major studies and sources over the last 20 years. This review does not present itself as an all inclusive review of all the EAC literature published during this period. Certain studies have been lost over the past years (John Sincavage; TARISM) and some studies, exclusively done by each Service (AD Study, AFSC Study by Wallender) are buried in Cost Libraries across the nation. Scarce travel funds and time constraints prohibited on site research at these libraries.

The following chapters will provide a literature review (Chapter 2), critical analysis of each study (Chapter 3), and conclusions about the research objectives and future research recommendations (Chapter 4).

II. Description of EAC Models, Studies, and Other Sources

In Chapter I an Estimate-at-Completion (EAC) was defined as the forecasted final contract cost. So what should this EAC contain? In one of the books written on C/SCSC, Quentin Fleming stated there are four factors a contractor must consider when developing an EAC:

> 1. The performance to date, BCWP, as related to the original plan, BCWS. This would involve evaluating the schedule performance such as a Schedule Performance Index does (Appendix A).
> 2. The actual costs to date, ACWP. This would include direct costs as well as indirect costs.
>
> 3. A projection of future performance. A look at future changes, additional tasks, problem areas, and uncertainties or risk in accomplishing the tasks.
>
> 4. An estimate of the cost of the remaining work on the contract.
>
> (22:114)

Whether a government cost analyst or a contractor is developing or analyzing an EAC, these factors should be present in order to have a comprehensive and meaningful EAC. The above factors are also evaluated in the DOD Joint Implementation Guide (JIG), Appendix E, Section IV (Analysis) criterion 6, with 19 questions focusing on the contractor development of an EAC (16: Appendix E.IV.6: E-13-14).

Considering the above factors Slemaker takes the definition of EAC to a finer level. He defines an EAC as an estimate of the actual work left plus the actual costs of

the work performed (ACWP) to date. This can be represented mathematically in the following formula:

$$\mathbf{EAC = CACWP + [[BAC-CBCWP] \times PPF]} \qquad (1)$$

Where CACWP refers to the cumulative cost to date and CBCWP is the cumulative "Earned Value" of the work actually accomplished. The difference between the BAC (Total Work) and the CBCWP is the work remaining. A Past Performance Factor (PPF) is a factor that indicates how the contractor has performed to date. The work remaining (in dollars) multiplied by the PPF will give the expected cost of the work remaining. The actual cumulative cost and the estimate of work remaining will produce an EAC (43:205-206).

There are two different methods used to formulate EACs: analytical and mathematical (43:205, 22:116-117). The analytical method is basically re-estimating the rest of the work from the lowest level of work tasks. This method is very time consuming with detailed calculations and intensive management reviews. The Joint Implementation Guide requires this type of estimate, a "grassroots" EAC, annually. The mathematical method requires the use of CPR or C/SSR data elements such as cumulative ACWP (actual cost), BAC,and BCWP (earned value) (43:208, 22:181).

A true analytical review or comprehensive EAC can only be performed by the contractor. He is the one that knows how he does the work, what tasks he must be done, and the internal ins and outs of performance (16:3-17). Because of time constraints, travel expense, and manpower limitations

the government relies upon the mathematical method for doing an EAC. Since a validated system assumes the data are reliable, data elements of the CPR are used to calculate an EAC.

Forecasting

Forecasting has been defined as "a process which has as its objective the prediction of future events or conditions" (31:3). EAC formulas predict a future event - the final cost. The EAC literature can be divided into three general categories of formulas or approaches for forecasting an EAC.

1. Indices or past performance factors
2. Regression equations
3. Other

Table 1 provides a general summary of the models and studies reviewed in this chapter. A "Study" is defined as research that compares different EAC formulas using Cost/Schedule performance data. "Models" present EAC formulas as single equations or a sequence of steps ortechniques to produce an EAC, but reference limited (one to five samples) or no empirical work supporting the formulas. An explanation of each column in Table 1 is provided below:

Column Heading	Explanation
Ref. #	Provides a reference number for each study. This number will be used as a cross reference throughout this thesis.

TABLE 1

SUMMARY OF EAC STUDIES AND MODELS

Ref #	Author	Year	EAC Formulas								Type of Contract		SER	ST
			INDEX					REGRESS.		OTHER				
			CPI	SPI	SCI	WT	O	L	NL	O	R&D	PROD		
1	El-Sabban	1973								X			A	M
2	Karsch	1974	X						X(2)		X(1)		AF	M,C
3	Holeman	1975	X				X						A	M
4	Karsch	1976	X						X(2)			X(13)	AF	F,C,M
5	Busse	1977								X	X(1)		AF	M
6	Hayes	1977	X						X	X	X(3)	X(2)	AF	C,F
7	Heydinger	1977	X			X	X		X		X(1)		AF	M,C
8	Weida	1977								X	X(22)		AF	M
9	Land Preston	1980	X						X		X*	X*	AF	C,F
10	Lollar	1980	X			X							AF	M
11	Covach	1981	X	X			X	X	X		X(14)	X(3)	N	C,M
12	Bright Howard	1981	X		X	X	X	X	X		X(11)		A	M,C
13	Chacko	1981								X			I	M
14	Blythe	1982	X			X				X	X(7)S	X(19)S	AF	C,M,F
15	Blythe	1984								X	X(7)S	X(19)S	AF	M,F
16	Price	1985	X			X					X(57)		AF	C
17	Cryer Balthazer	1986				X	X				X(7)S	X(19)S	AF	C,F
18	Wallender	1986				X							AF	F
19	Totaro	1987				X					X(6)*		AF	M
20	Reidel Chance	1989	X		X	X	X				X(16)	X(40)	AF	F,C

Acronym Definition:

- A - Army
- AF - Air Force
- C - Comparative Study
- CPI - Cost Performance Index
- F - Follow-on Study
- I - Independent
- L - Linear Single Variable Model
- M - Model/Approach
- N - Navy
- * - 30 Total Programs (no breakout)
- NL - Non Linear Single Variable Model
- O - Other Methods
- PROD - Production Contracts
- R&D - Research and Development Contracts
- S - Same Database
- SCI - Schedule Index x Cost Index
- SER - Armed Services
- SPI - Schedule Performance Index
- ST - Study Type
- WT - Weighted Per Cent for Cost and Schedule Indices

Author	Self explanatory.
Year	Self explanatory.
CPI	Formulas using the Cost Performance Index.
SPI	Formulas using a Schedule Performance Index.
SCI	Formulas using the CPI multiplied by the SPI.
WT	Formulas using a weighting for Schedule and Cost indices added together: W_1 SPI + W_2 CPI = 1.
O	Other methods or combinations in a category.
L	Refers to linear regression models, with the number of independent variables in parentheses.
NL	Non linear regression models with the number of independent variables in parentheses.
	Type of contract the study or model used for illustration or comparison. R&D refers to Research and Development and engineering and Material (formally FSD) contracts. PROD refers to Production contracts.
SER	The branch of the Armed Services that contracted or performed the study.
ST	Indicates the different structures used in the studies.
	C - A study that compares different formulas.
	M - A model or approach is developed or modified.
	F - Further research is done using a previous study as its base.

Each study and model is categorized based upon the EAC formulas within the research study or sources.

The remainder of the chapter describes each model and study listed in Table 1. Each study or model subheading includes the year of the study and the reference number from

Table 1. Past Performance Factors (PPF) research is addressed first with regression analysis formulas next. The last category is Other which will look at research into different techniques. For each model or study, the equations, evaluation criteria, and results (if appropriate) are described.

Past Performance Factors

Past Performance Factors (PPF) are ratios of BCWS, BCWP, and ACWP. CPI, SPI, CV%, and SV% are the common ratios and are used with current month, moving average month or cumulative data. The "factors" can be ratios used alone or in combinations in order to produce an EAC. The mathematical formulas for the above ratios are presented in Appendix B.

The two primary indices are the CPI and SPI. The stability of the CPI was the focus of an Air Force Institute of Technology (AFIT) 1990 Masters' Thesis by Kirk Payne. He evaluated the CPI stability (within + or - 10%) at the 50% completion point of a contract (39:1-2). The CPI was shown to be stable at 50% and lower points of completion depending upon which method was used (39:22-25). So as the contract progresses the Cumulative CPI is an increasingly stable indicator of performance.

As stated above, the indices can represent different time periods. Moving averages are averaged data for whatever time period is chosen. EAC formulas usually use three, six

and 12 months as time periods. The averaging method uses two techniques: Average of Ratios, and Ratio of Sums. The Average of Ratios technique calculates each monthly index then divides by the number of months.

$$CPI_n = \Sigma \ (BCWP \ / \ ACWP) \ / \ n \qquad (2)$$

$$SPI_n = \Sigma \ (BCWP \ / \ BCWS) \ / \ n \qquad (3)$$

Where

n = number of months

This method will be indicated in this study by the index name with the period of time as a subscript (CPI_3, SPI_{12}).

The second method is a Ratio of Sums of monthly data through the chosen time period.

$$\overline{CPI}_n = \Sigma \ BCWP \ / \ \Sigma \ ACWP \qquad (4)$$

$$\overline{SPI}_n = \Sigma \ BCWP \ / \ \Sigma \ BCWS \qquad (5)$$

This method will be indicated by a bar over the index with the subscript indicating the period of time ($\overline{CPI}_3$, $\overline{SPI}_{12}$) (12:23-24).

Combinations of the indices are also used to produce performance factors. The CPI and SPI may be either multiplied or added together. Their product is sometimes termed the "Schedule-Cost-Index" (SCI). When added, weights are often assigned to each index, such that the sum of the weights add to one ($W_1 + W_2 = 1$).

$$SCI = SPI \times CPI \qquad (6)$$

$$\text{Weighted Index} = W_1 \ (SPI) + W_2 \ (CPI) \qquad (7)$$

The different variations of these individual methods and combinations present a multitude of choices for calculating a past performance factor.

Holeman Model (1975:3).

One of the earliest EAC models studies was done by J.B. Holeman (1975). Holeman categorized cost estimation as either parametric (based on cost estimating relationships (CER)), or engineering ("bottom up"). Holeman then proposed another approach category. This "EAC approach" would incorporate data from the contract and managerial judgment which he thought would produce a better estimate of the final contract cost (27:2-3). Three methods were presented.

The first method used the BAC of the contract and multiplied it by the cumulative cost performance index (CPI_p) (27:10). (Since $CPI_p = 1 / CPI_e$, dividing the BAC by the CPI_e is an equivalent method.)

$$EAC = BAC \times CPI_p \qquad (8)$$

$$EAC = BAC / CPI_e \qquad (9)$$

Equations 8 and 9 will give the same EAC.

The second method used judgmental evaluation of contract changes, inflation, schedule variations, overhead changes and unexpected technical problems (27:17-21). Of these five factors, contract changes contributes "almost half of the average weapon system cost growth" according to a Government Accounting Office Report in 1973 (27:16). The formula

requires subjective estimates of four of the factors be determined by qualified individuals and assumes that technical problems are reflected in the CPI_p.

$$EAC = ACWP + [(BAC - BCWP) \times PPF] + CONTRACT\ CHANGES + SCHEDULE\ VARIATIONS \qquad (10)$$

Where

$PPF = CPI_p$ + Inflation (decimal) + Overhead (decimal)

CPI_p = Unexpected Technical Problems

(27:22)

Example:

Contract changes = \$.8M

Inflation change = .04

Overhead increase = .30

$CPI_p = 1.15$

Schedule variations = \$.6M

$EAC = ACWP + (BAC-BCWP)/(1.15+.04+.3) + .8M + .6M$

Holemans' third method involves a set of steps to determine a range for the performance factor. Ranges for the lower level work element or "task CPI" are determined by using a three-point, cumulative %, or a probability distribution method. Using the three point method, three lower level tasks would have a high, most likely, and worst value for the CPI for each task (27:24). The second step is to do a simulation using the CPI ranges and a Monte Carlo sampling technique. The different combination of CPIs from the ranges established will produce a large number of

estimates. The estimates are grouped into ranges with relative and cumulative frequencies calculated and plotted against the EAC dollars. The last step is to analyze the data and graph to get an average EAC or a range of EACs (27:24-29). This method provides flexibility to the EAC.

Lollar Model (1980:10).

A less flexible model presentation was done by James Lollar. Lollar attempted to avoid the judgmental problem of determining the weights assigned to CPI and SPI (32:5). In his model (Equation 11), the weights are determined by adding the absolute values of CV% and SV% and taking the respective share of the Total percent.

$$\mathbf{EAC = ACWP + (BAC-BCWP) / PPF} \tag{11}$$

Where

$PPF = CVf(CPI) + SVf(SPI)$

$CVf = |CV\%| / (|CV\%| + |SV\%|)$

$SVf = |SV\%| / (|CV\%| + |SV\%|)$

The "Conventional Formula" of Lollars' project is Equation 9 (32:11-12).

Example:

$CV = -10\%$ $SV = 25\%$ $ACWP = 55$ $BAC = 200$

$BCWP = 50$ $CPI = .91$ $SPI = 1.10$

$CVf = 10/35 = .28$ $SVf = 25/35 = .72$

$PPF = .28(.91) + .72(1.1) = 1.05$

$EAC = 55 + (200-50)/1.05 \approx 197.86$

Totaro Model (1987:19).

Totaro also proposed a model which involved the weights of indices as in Equation 7. In his model, the weights change as the contract progresses and are a function of percent complete (45:29-30).

$$\mathbf{EAC} = (\mathbf{BAC}-\mathbf{BCWP}) / [.25-.25(\mathbf{BCWP}/\mathbf{BAC})]\mathbf{SPI} + [.75+.25(\mathbf{BCWP}/\mathbf{BAC})]\mathbf{CPI} + \mathbf{ACWP} \quad (12)$$

Where

BCWP / BAC = % Complete

% SPI + % CPI = 100%

(45:31)

The initial percentages are determined by the analyst depending upon program goals and knowledge. The ultimate goal of the formula is that as the contract approaches completion, SPI has a decreasing effect and CPI has an increasing effect on the performance factor (45:32).

Example:

Using the same data as in the Lollar example.

EAC = 200-50/PPF + 55

PPF=[.25-.25(50/200)]1.1 + [.75+.25(50/200)].91

EAC = 150/.945 + 55 = 213.73

Blythe 1982 Study (1982:14).

A major problem with the models proposed by Holeman, Lollar, and Totaro is that they were not evaluated against actual programs. In 1982 Blythe compared three models using actual program data. These models were the Lollar Model

(Equation 11), Parker Model, and the "Conventional Formula" (Equation 9) - as well as the contractors' EAC (6:6-7). The Parker Model was developed in 1980 and has fixed weights for SPI and CPI but the model by Parker was not found during the research period (13:3).

Parker Model:

$$\mathbf{EAC = ACWP + (BAC-BCWP) / (.3\ SPI + .7CPI)} \qquad (13)$$

(6:4,9)

Blythe evaluated the models using data from 26 programs (7 R&D, 19 Production) and compared the results at six percent completion points. In order to standardize the data with respect to contract changes, the final report BAC was used for each completion point. Any difference between the final BAC and the actual BAC at each point was added to or subtracted from the calculated EAC at that completion point. The actual BAC was used to calculate the percent complete (6:4-5).

The contractor's EAC and the Lollar Model were compared first. The Lollar Model was closer to the final BAC only 37% of the time. The Parker Model was then run using different combinations of weightings (.1 increments). Based on the lowest coefficient of variation (Std. Deviation / mean), the study concludes that weightings of 20% SPI and 80% CPI provided the best estimates among the combinations. All models and weighting combinations were then compared with the 0% SPI and 100% CPI representing the "Conventional Formula". The method for selecting the most accurate model

is not clear but appears to be an evaluation including the smallest standard deviation, mean closest to the BAC, and the range of the estimates (6:6-8).

The conclusions of the study were that the Lollar Model was the least accurate with the contractor EAC being the most accurate. The closer to contract completion (95% completion point) all models produced accurate estimates (6:7). The contractor EAC was consistently under estimating and showed a small standard deviation which interested Blythes' associates to expand on these characteristics.

Blythe 1984 Study (1984:15).

Based on the above characteristics of the contractor's EAC, Blythe extended his research in 1984 to develop an adjustment factor based on the contractor's EAC (5:2). The factors were developed by regression analysis. Parts of his report have been lost (Appendix A showing details of formula) but the formula produced is shown below:

$$\mathbf{AEAC = EAC / [.9108 + .0892\ (BCWP / BAC)]} \qquad (14)$$

(5:3)

The AEAC is the "adjusted contractor EAC".

Blythe also developed a formula to calculate the standard error (SE) of the contractor's EAC:

$$\mathbf{SE = EAC \times [.1289 - .0925(BCWP/BAC)]} \qquad (15)$$

The SE could then be used to calculate a confidence interval for the adjusted EAC:

$$\textbf{AEAC} \pm \textbf{Z(SE)} \qquad (16)$$

(5:3)

Z represents the value from a normal distribution table.

Example:

BCWP = 55 BAC = 250 Contractor's EAC = 275

AEAC = 275/[.9108 + .0892(55/250)] = 295.57

SE = 275 [.1289-.0925(55/250)] = 29.85

Cryer and Balthazer Study (1986:17).

Cryer and Balthazer looked at the database used by Blythe and hypothesized that evaluating the database by R&D and production contracts would validate different models for each phase (13:1). Other than stratifying the database, the same models and methods were used (13:2-4). The standard error of the estimate, standard deviation, and coefficient of variation were used to evaluate the models' predictive accuracy (13:4-5). Results agreed with those of Blythe in that the contractor's EAC was the best overall predictor. The adjustment factor models that Blythe calculated by regression analysis were different in the Balthazer and Cryer study.

However, Balthazer and Cryer findings on the best weights were different from Blythes'. Based on the coefficient of variation, the .1 SPI and .9 CPI had the lowest coefficient of variation for the combined and production but not for R&D. Weights of .2 SPI and .8 CPI were second with the best R&D coefficient of variation. The .3 SPI and .7 CPI weights

were the next best combination. All three combinations were within 1% of each other. If standard error of the estimate was used for selection, the .4 SPI and .6 CPI combination was the lowest for combined contracts but no significance was stated by the authors (13:5).

Wallender Study (1986:18).

In 1986 Wallender wrote a paper justifying what was called the "Hq AFSC EAC Formula" (46:1).

$$\mathbf{EAC = ACWP + (BAC\text{-}BCWP)/(.2\ SPI+.8\ CPI)} \qquad (17)$$

(BAC excludes MR if MR is not expected to be used.)

(Wallender:1)

Blythes'study (1982), an AFSC study led by Wallender, and an Armament Division (AD) study done by Rutledge and Dinato were given as evidence for the weights (46:2-3).

The Hq AFSC Study compared 44 contracts using EAC calculations based on the 20% and 80% weighting. These contracts were from the Ballistic Missile Office (BMO) which was considered as having the best EAC analysis techniques based upon a May-June 1985 Program Financial Review (PFR) conducted by Hq AFSC (46:2). Of the contracts compared, all but five were within 10% of the BMO estimates using the AFSC formula (46:2).

The AD study used a database of two Production and 13 R&D contracts to evaluate the AFSC Model (Equation 17) and a model using SCI which was called the "OSD model" (46:3).

$$\mathbf{EAC = ACWP + (BAC\text{-}BCWP)/\ (CPI \times SPI)} \qquad (18)$$

(46:3)

A percent variance was calculated which consisted of the difference between the calculated EAC and final ACWP + MR divided by the final ACWP + MR times 100%.

Example:

EAC = 100

ACWP = 110

MR = 5

% Variance = [(100 - 115) / 115] 100% = -13%

The variance was calculated at 25, 50, and 75% completion points. Results showed 77% of the contracts were within ± 15% of ACWP + MR at 25% complete, 86% were within ± 10% at 50% complete, and 93% were within ± 8% at 75% complete. The study showed the OSD Model EACs were 10-12% higher than the AFSC formula (46:3). The Wallender paper was the only documentation that could be found for the AD and AFSC studies.

Price Study (1985:16).

In 1985 James Price did a Masters Thesis at the Air Force Institute of Technology comparing EAC formulas found in the Cost Performance Report Analysis (CPRA) program used by financial analysts in the Air Force Wright Aeronautical Laboratories (AFWAL) at Wright-Patterson AFB. The CPRA program had six formulas but Price excluded the formula using trend extension based on the regression of ACWP. The five formulas are presented below:

$$EAC = ACWP + (BAC - BCWP) / CPI_{e\ Cur} \tag{19}$$

$$EAC = ACWP + (BAC - BCWP) / CPI_{e\ Cum} \tag{20}$$

$$EAC = ACWP + (BAC - BCWP) / CPI_{3}\text{*(See Appendix B)} \tag{21}$$

$$EAC = ACWP + ETC \tag{22}$$

Where

ETC = [100-(Cost Var. %)+.75(Schdule Var. %)] x BCWR / 100

$$EAC = EACC + ETCS \tag{23}$$

Where

EACC = (.12 x Eq.18) + (.64 x Eq.19) + (.24 x Eq.20)

ETCS = (months behind Schedule) x ACWP Rate x .75

ACWP Rate = ACWP/Total contract completed months

(40:10-12)

Price used 57 on-going R&D programs as his database (Price:15). The models were evaluated by regressing ACWP against the calculated EAC. The highest coefficient of determination (R^2) was used to determine the best predictor (40:27). Results showed Equation 21 to be the best predictor (40:31).

Reidel and Chance Study (1989:20).

A follow-on study to the Price research was done by Chance and Reidel (Reidel:2). This study was a comparative study of the EAC formulas (Equations 19, 20, 21) in Prices' thesis, two equations (Equations 9, 18) taught in the Defense Systems Management College (DSMC) Contractor Performance Measurement course, and two weighted formulas

(Equations 17, 24) (41:4-6). Algebraically, Equations 9 and 20 are the same equation.

Equation 9:

$$EAC = BAC \times ACWP_{Cum} / BCWP_{Cum}$$

Equation 20:

$$EAC = ACWP + (BAC - BCWP_{Cum}) \times (ACWP_{Cum} / BCWP_{Cum})$$

$$EAC = BAC \times ACWP_{Cum} / BCWP_{Cum}$$

$$\mathbf{EAC = ACWP + (BAC - BCWP) / [(x)CPI + (1-x)SPI]} \quad (24)$$

Where

x = % complete

(41:5-6)

This study used 16 R&D contracts and 40 Production contracts consisting of aircraft, avionics, and engine (41:29-70). The evaluation looked at different percent completion points (25%,50%,75%,100%) and compared the final ACWP against the calculated EAC. The methodology used for picking the "best" predictor was the lowest Average Absolute percent deviation with a crosscheck using Average Rank Order at the specific percent completion points and for overall program (41:18-20).

Results of the study are shown in Table 2 (41:29-70). The parenthesis indicates the number of programs used in the calculations. The numbers represent the equations, as numbered in this thesis, and represents the best predicting formula for that completion stage. Since Equation 9 and 20

TABLE 2

SUMMARY OF REIDEL AND CHANCE STUDY

R&D	Percent Complete 25%	50%	75%	100%	Overall
Aircraft (7)	18	21	21	17	18,20
Avionics (5)	18,24	21	21	17,18,20	18,21
Engine (4)	19	18	21	21	18,21
Production					
Aircraft (23)	18	21	18	17,20	18,17
Avionics (16)	17	18	17	18	17,20
Engine (9)	24	20	18,24	24	17,20

Note: The numbers listed in each cell refer to the EAC equation number assigned in this research. The following list details the index (Past Performance Factor) used in each formula:

Equation	Index
17	(.2)Cumulative SPIc + (.8)Cumulative CPIc
18	Cumulative CPIc x Cumulative SPIc
19	Monthly CPIc
20	Cumulative CPIc
21	3 Month Average CPIc (See Appendix B)
24	(X)Cumulative CPIc x (1-X)Cumulative SPIc

give the same results only Equation 20 will be listed in Table 2.

<u>Covach (NAVSEA) Study (1981:11).</u>

The two DSMC formulas were originally obtained from a Navy sponsored contract to ManTech International Corporation titled <u>A Study to Determine Indicators and Methods to Compute Estimate at Completion</u> (12:1). This study was the basis for the Defense Systems Management College (DSMC) <u>Modular 6</u> of the <u>Contractor Performance Measurement Course</u> (14:6). The study evaluated performance factor formulas, regression models, and the use of manpower as an estimator for forecasting EACs (12:1-2).

The evaluation criteria for the ManTech study were based on assessing three basic principles.

1. Accuracy - A method's estimate of costs at completion (EAC) should generally be equal or close to the contractor's actual cost at completion.

2. Timeliness - A method should be capable of producing a reliable EAC as early as possible in the life of the contract.

3. Stability - A method should not produce EACs which, on a month to month basis, vary widely.

(12:21)

Three methods were used to evaluate 12 formulas using a database of six Navy programs.

$$EAC = ACWP + CPI_{FCur}\ (BCWR) \qquad (25)$$

$$EAC = ACWP + CPI_{F3}\ (BCWR) \qquad (26)$$

$$EAC = ACWP + CPI_{F6}\ (BCWR) \qquad (27)$$

$$EAC = ACWP + CPI_{F12}\ (BCWR) \qquad (28)$$

$$EAC = ACWP + CPI_P\ (BCWR) \qquad (29)$$

$$EAC = ACWP + (CPI_P\ /\ SPI)BCWR \qquad (30)$$

$$EAC = CPI_{P3}\ (BAC) \qquad (31)$$

$$EAC = BAC/SPI \qquad (32)$$

$$EAC = \overline{CPI}_{P3}\ (BAC) \qquad (33)$$

$$EAC = \overline{CPI}_{P3}\ (BCWR) + ACWP \qquad (34)$$

$$EAC = \overline{CPI}_{P6}\ (BAC) \qquad (35)$$

$$EAC = \overline{CPI}_{P6}\ (BCWR) + ACWP \qquad (36)$$

(12:23-24)

The evaluation used three methods: 10%, BAC, and LRE. The "10% method" compared the calculated EAC to the final ACWP to see if it is within ± 10% of the ACWP. If the calculated EAC is within this range more than 75% of the time, the formula was classified as a success. Meeting the criteria less than 50% of the time was classified as a failure and between 75% and 50% was rated indifferent. The "BAC method" looked at where the EAC fell between the BAC and ACWP. If the EAC fell on the high side of the BAC or ACWP then the distance should be less than the difference between BAC and ACWP for a success. The "LRE" method compared the contractor's EAC and the calculated EAC to the ACWP. If the EAC calculated was better than the contractors EAC it was successful. This was done on a monthly basis. The life of a contract was then broken into quintals (20% increments) and the formulas evaluated by phases (12:24-27).

A scoring system was established giving a numerical score of 1 for successes, 0 for indifference, and -1 for failures. Three phases of contract completion were defined with the early phase being the first 2 quintals (20%), the middle being the middle 3 quintals, and the late phase being the last two quintals. The formulas were evaluated by scoring them by the three methods above and by phases (12:28-31). Results by stage are listed below:

Early	Middle	Late
Eq. 29,30,34	Eq. 27,29,30,34	Eq. 28,34,36

(12:62)

The regression evaluation used three regression approaches against four different curves (linear,power, exponential, log) plus the "New SAMSO" model which will be discussed later (12:31-35). The same evaluation methods and database were used. Results showed three approaches and curves were best relative to the regression equations only. The first method was regressing ACWP against BCWP and computing ACWP where BCWP = BAC with a linear curve. The second method was regressing the CPI as a function of time and matching the final CPI to the BAC . The curve equation was a power function equation. The last method was to regress ACWP and BCWP to time and find the final time where BCWP = BAC and using this time in the ACWP regression

equation to calculate an EAC. This curve used was an exponential equation (12:30-35).

Additional programs (9 R&D, 2 Prod.) were added to the database in order to do an analysis of manpower as an indicator for calculating EACs. The study also looked at developing EACs from lower level Work Breakdown Structure tasks (Level 2). Nothing was found to indicate manpower would be a good indicator to use for EAC formulas. Investigation of developing estimates at lower level tasks did not provide a better EAC (12:20).

A final aspect of this study involved interviews with leaders in the C/S community. Results revealed the following opinions:

1. Trends rarely reverse themselves.
2. Managers want to use simple forecasting methods.
3. Manpower loading data were under utilized by analysts.
4. Initial trouble or problems appear in the schedule area.

(12:7)

An update to the NAVSEA study was published in 1982 (24:1). The extended research increased the database to 21 programs and evaluated a different EAC method called the "Range Method". Results of this study did not change the rankings of the formulas in the earlier study or provide a better method. Further work with regression analysis was done by adding three hyperbolic curve equations and using the same regression approaches.

$$Y = a + b / X \tag{37}$$

$$Y = 1 / (a + b X) \tag{38}$$

$$1 / Y = a + b / X \tag{39}$$

(24:23)

The update produced two other regression approaches that should be considered. The two approaches used Equation 37 and the second and third methods stated above in the regression review for this study (24:24).

Land and Preston Study (1980:9).

Some of the Services have developed computer programs that do CPR and C/SSR analysis. These programs usually have many EAC formulas from which the analyst can pick. One of these programs is the Automated Financial Analysis Program at ESD. The program allows the analyst to pick three EAC formulas that will give him/her a range of values for an EAC (1:64-65).

General equation is EAC = ACWP + ETC

$$ETC = (1 - CVI_{Cur})BCWR \tag{40}$$

Where

$CVI = CV / BCWP$

$$ETC = [1 - (CVI_{m} + CVI_{m-1} + CVI_{m-2}/3)]BCWR \tag{41}$$

Where

m = current monthly data

ETC = Performance Factor determined by analyst

$$ETC = (1 - CVI)BCWR \tag{42}$$

$$ETC = [1 - (BCWP_3 - ACWP_3 / BCWP_3)]\ BCWR \tag{43}$$

Where

$$BCWP_3 = BCWP_{Cur} + BCWP_{Cur-1} + BCWP_{Cur-2}$$

$$ACWP_3 = ACWP_{Cur} + ACWP_{Cur-1} + ACWP_{Cur-2}$$

$$ETC = [1 - CVW(CVI) + SVW(SVI)]BCWR \qquad (44)$$

Where

CVW = Cost Variance Weight

SVW = Schedule Variance Weight

(30:23-27, 1:A2-5-6)

This ESD program (linear models) and the Karsch Model (a nonlinear model reviewed in the regression section) were compared in a Masters Thesis by Captain Land and Captain Preston (30:1). The methodology used for the accuracy of prediction was the absolute value of (EAC-ACWP)/ACWP or the error % (30:32). The research used 20 programs which were a mix of R&D and Production contracts. Five more contracts were added in order to calculate an average value for b_2 which is part of the Karsch model. The research showed the following results:

1. A non linear model was no more accurate than the linear model.
2. At different percent completion points the non linear model was no more accurate than the linear model.
3. The b_2 value for aircraft should be 1.033 and the b_2 number is very critical to the accuracy of the EAC calculation.

(30:40-49)

Bright and Howard Study (1981:12).

Another computerized program is the Automated Contractor Performance Measurement System (ACPMS) used by the Army Missile Command (MICOM) (7:2). Bright and Howard looked at the ACPMS formulas and compared them to an "improved method" of developing a performance factor. This method developed a performance factor by multiplying the CPI by the SPI (7:17).

$$EAC = ACWP + (BAC - BCWP) / (CPI \times SPI) \tag{45}$$

(7:17)

The formulas used in the ACPMS are as follows:

General equation $EAC = ACWP + (BAC - BCWP)P$

$$P = 1 / \overline{CPI}_3 \tag{46}$$

$$P = 1 / \overline{CPI}_6 \tag{47}$$

$$P = 1 / \overline{CPI}_{12} \tag{48}$$

$$P = 1 / CPI \tag{49}$$

P = Determined by the analyst

The following formulas weight the indices and have the same general formula as above except for:

$$P = 1 / A$$

$$A = [W_1(SPI) + W_2(CPI)] / (W_1 + W_2) \tag{50}$$

Where

$W_1 + W_2 = 1$

Different weight combination:

$$W_1 = .5 \quad W_2 = .5 \tag{51}$$

$$W_1 = .75 \quad W_2 = .25 \tag{52}$$

$$W_1 = 1.0 \quad W_2 = 0.0 \quad \text{same as } 1 / SPI \tag{53}$$

Two regression approaches (See Appendix C for Approaches). (7:4-7)

The database consisted of 11 Army R&D contracts which were evaluated at different per cent completion points. Data were adjusted for rebaselining, additional scope, and contracts not completed (7:10-12). This normalized the ACWP and allowed the monthly calculation of EAC to be compared to it. The forecasts were scored by month for the best forecast (1 point) and fractions of a point were given for estimates closest to the best EAC for that month (7:14-15).

A separate analysis of different CPI x SPI combinations resulted in a six month moving average for CPI and a cumulative SPI being the best predictors of final cost (7:17). This equation was then added to the other ACPMS formulas for comparison.

The results of the study showed the SPI formulas, regression models, and CPI x SPI did better in the first 30% of the contract. After 30% the cumulative CPI and moving average CPI did better at predicting. The CPI x SPI combination did excellent from 31% to 80% complete and was rated good after 80% to contract completion (7:15-19).

Other sources of EAC formulas found during this research were the System 361/362/363 courses taught at The Air Force Institute of Technology (AFIT) and Performance Analyzer computer program.

The Performance Analyzer was developed to analyze CPR and C/SSR reports (42:i). The EAC section contains seven

different EAC formulas ranging from CPI moving averages to regression models (42:85-88). The formulas do not include MR but the program allows the analyst to add MR after the EAC is calculated (42:40). The Air Force Institute of Technology provides a list of EAC formulas to students attending during C/S courses. These equations are not developed by AFIT but gleaned from other studies. But the number of analysts that go through the courses warrants mention of the formulas presented there. Appendix C shows the formulas for the computer program and AFIT courses.

This has been a literature review of models, studies, and sources of EAC formulas that use Past Performance factors to forecast final costs. Different formulas were found to be better predictors at certain percent completion points. Different weighting combinations were also tested to find the best predicting combination. The next category listed in Table 1 is Regression Analysis.

Regression Analysis

Regression analysis looks at the statistical relationship between two variables. The variables consist of a dependent variable (Y) and an independent variable (X) (37:23-26). The relationship between the dependent variable and the independent variable can exhibit a linear relationship (straight line) of nonlinear relationship (curve). Neter explains that there are three types of regression models - linear, intrinsically linear, and nonlinear. The linear

models have a linear relationship with respect to the parameters (coefficients and y-intercept). Intrinsically linear implies the parameters are nonlinear but can be transformed by mathematical manipulation (logs, square, inverse, square root) into linear parameters. Nonlinear model parameters can not be transformed (37:142-145, 550-551). A regression equation can have one independent variable or multiple independent variables to explain the relationship.

Single Variable Regression Equation (Linear):

$$Y_i = B_0 + B_1 X_i + E_i \tag{54}$$

Where

Y_i - Calculated value

B_0 - Y intercept

B_1 - Slope of line

X_i - Value of X

E_i - Random Error

(37:31-34)

Multiple Variable (Linear)

$$Y_i = B_0 + B_1 X_1 + B_2 X_2 + E_i \tag{55}$$

(37:31-34)

One of the assumptions of linear regression analysis is that the expected value of the random error term is zero (37:32). With this assumption the random error term will drop out of the above formulas. Computer analysis is required for fitting the line and doing the calculations for

the necessary statistics to analyze the results (standard error, R^2, F-test, t-test).

Karsch Study (1974:2).

Computer analysis programs for Cost/Schedule reports such as CPRA (Price Thesis), ACPMS (Army), and Performance Analyzer include linear and nonlinear regression models (40:11, 7:7, 42:88). One of the regression models was developed by Karsch in 1974.

Karsch Model:

$$Y = b_1 X b^2 \tag{56}$$

(28:13)

One of the reasons behind this formula was long term growth of ACWP and BCWP was shown to be nonlinear. The nomenclature b_1 and b_2 are non-dimensional growth factors (28:13-14). This model also has a constrained mode where b_2 is held constant and an unconstrained mode where it is calculated each month (28:16).

A comparative study was done with one sample using percent cum variance, constrained, and unconstrained models. The selection criteria was the method that generated an EAC closest to the final ACWP the earliest (28:18). The results showed that the constrained model was closer to the final ACWP up to the 93% completion point. All three models were close at the 98% completion point with percent cum cost variance better after 98% completion (28:23).

Since the constrained model uses b_2 as a constant value, Karsch conducted another study in 1976 to determine a value range for b_2 for production contracts (29:1). A database of 13 production aircraft and missile contracts was used to compare the same formulas as in Karschs' 1974 study (29:3). The results for aircraft data showed that up to 88% completion the constrained model ($b_2 = 1.053$) was better. From 88% to 98% contract completion both Karsch models were better predictors and from 98% the percent cum variance formula was better. When comparing the constrained to the contractor EAC the contractor EAC was better after 95% completion (29:5-9).

The missile data showed the constrained model ($b_2 = 1.041$) a better predictor up to 75% completion with % cum variance better after this point. When the contractor EAC and the constrained model were compared, the contractor EAC was better between 0-20% and 88-100% (29:11-15).

When evaluating the value for b_2, the range for the production contracts was from .94-1.13 with the most common values between 1.0-1.1. The range did not differ significantly between aircraft and missile contracts (29:16).

Heydinger (SAMSO) Study (1977:7).

The Space and Missile Systems Organization (SAMSO) produced a model that also used a regression technique (26:8). The current month BCWP and the previous five months

BCWP were regressed against time by Least Squares regression. The same procedure is done for the ACWP. The point where BCWP equals BAC is the point where the ACWP regression line is read. This ACWP value is the EAC (26:8-9). This method along with the Karsch model (Equation 56 constrained) and ESD automated program Equations 40, 41, 42, 43 were compared against an unknown number of data points (26:11-20). The results showed the Karsch model (Equation 56) gave better predictions from the third to the seventh month and 27th to 42th month with the ESD model Equation 41 providing better results between months 8-26 (26:18).

This study also proposed a new SAMSO model. Curves were fitted to the expenditure data with the best fit resulting from a modified Erlang equation.

$$Y = a\,x^{b}\,e^{cx} \tag{57}$$

Where

x = number of cumulative months

Y= ACWP, BCWP or BCWS

The ACWP, BCWP and BCWS are regressed with this equation and the same basic SAMSO procedures are followed except now schedule can be projected (BCWS = BAC) (26:22-23).

The original SAMSO procedures are followed with the BCWP regressed by the Erlang equation. The BAC time (T_{BAC}) is where the BCWP is equal to the BAC. The time is ACWP regression equation and the value at T_{BAC} is the EAC. Regressing BCWS to the BAC line will give a schedule variance in time (26:21-21A).

Using the constrained "New SAMSO" model against the above equations the results were interpreted by the author that the New SAMSO was a better model for predicting the EAC (26:28).

The regression type of models require the use of a computer as compared to a simple calculator with the Past Performance Factor models. Regression and performance indices are the two major categories of models but there have been other approaches tried in the search for a better forecasting model.

Other Techniques

This category contains a mixture of models and approaches which are seldom used. One of the areas has been in the use of Bayesian probability to predict EACs.

El-Sabban Study (1973:1).

The approach involves the determination of probabilities of events happening (prior probability) and with additional information (new CPR) these probabilities can be updated (posterior probability) (33:725). The posterior probabilities are conditional probabilities and are centered around Bayes Theorem.

$$P(F/E) = P(F_i)\ P\ (E/F_i)\ /E^{n}_{i=1}\ P(F_i)\ P(E/F) \qquad (58)$$

Where

F_i - n mutually exclusive and exhaustive events

E - a known outcome

$P(F_i)$ - prior probability

$P(E/F_i)$ - conditional probability of E given F_i
occurred

(33:726-727)

In 1973 Zaki El-Sabban proposed the use of Bayesian probability to calculate an EAC (20:1-2). The procedure derives a mean value (μ) that is the EAC.

El-Sabban Model:

$$E(\mu) = c\ \mu_a\ \sigma_o^2 + \mu_o\ c^2\ \sigma_a^2\ /\ (\ \sigma_o^2 + c^2\sigma_a^2\ ) \qquad (59)$$

Where

μ_a = ACWP

μ_o = BAC

$c = \mu_o$ / BCWP

$\sigma_a = .1 / \mu_a$

$\sigma_o = .05 / \mu_o$

(20:6)

The variance could also be calculated using the following formula.

$$V(\mu) = c_2\ \sigma_o^2\ \sigma_a^2\ /\ (\ \sigma_o^2 + c^2\ \sigma_a^2\ ) \qquad (60)$$

Where

$\sigma = (V)^{.5}$

(20:8)

This would provide an EAC and a range which could be updated by each monthly CPR.

The only other study that could be found relating to Bayesian probability was done by Hayes in 1977 (25:5). The study proposed corrections to El-Sabban's methodology in that BCWS should be used for prior probability instead of

ACWP and ACWP should be used for updating posterior probabilities (25:42).

This study compared the Karsch model(Equation 56), Bayesian approach with Hayes corrections (Equation 59), and the cumulative current percent cost variance model (Equation 9) used in the Karsch studies (25:43-44). A data base of three R&D and two Production programs were used (25:45). The evaluation was based on how soon a formula could predict the final cost. The results showed the Karsch model was a better predictor three out of five times followed by the Bayesian method (25:69).

Time Series Analysis.

Time-series analysis was another area looked at for EAC formulation. Time-series analysis can be defined as "a collection of observations made sequentially in time" (11:4). Moving averages, exponential smoothing, and regression analysis are different methods used in forecasting in time-series analysis (10:223). One of the disadvantages is the method takes a large amount of data points to work well.

There is not much evidence of the above procedure being used extensively. Sincavage did a study called TSARISM: Time Series Analysis for Army Internal Systems Management in 1974. Research into libraries and even contacting Sincavage could not produce a copy of this study . A paper by Ellsworth and Olsen did provide evidence that the B-1 SPO

(Special Program Office) in Los Angelos was using a time series analysis method as one of their EAC techniques (38:10). The approach used a computer program called GETSA to generate the EACs.

$$F_t = \text{Sigma } S_{t-1} + (1-\text{Sigma})\ F_{t-1} \qquad (61)$$

Where

F_t = forecast for time t

F_{t-1} = forecast for time t-1

S_{t-1} = cost for period t-1

Sigma = smoothing constant (0-1)

(38:11)

The Olsen paper explained the various methods and computer programs used by the SPO to come up with an EAC. Regression analysis, "grassroots" estimates, trend extension analysis, and modified exponential smoothing (Time-series) were used by the SPO (38:8-13). The paper acknowledged the importance of using more than one method, the use of judgment, and documentation in the development of a forecast (38:23).

Busse Model (1977;5).

Other methods have also been published such as the Busse Model. This model was based on the sensitivity of ACWP to BCWP (8:22). This sensitivity factor ($\bar{e}$) is the driving force of the model.

$$EAC = Z(BAC)^{\bar{e}} \qquad (62)$$

Where

$$\bar{e} = (ACWP_{Cur} / ACWP) / (BCWP_{Cur} / BCWP)$$

$$\bar{Z} = ACWP/(BCWP)^{\bar{e}}$$

(8:26-27)

Chacko Study (1981:13).

Chacko proposed an approach called the "adaptive" forecasting approach in which the model is fitted to the data rather than the reverse (9:75). This approach eliminates the concern about the linearity of the data (9:75). It utilizes a computer program called MESGRO. A new equation is calculated for the next month and adjusted by the difference between the forecast and actual cost. According to the author, it takes about five data points to stabilize and produces accurate estimates must faster in the short term (9:78-81). There was little detail in the study which was taken from a periodical. The suspicion is that the study was condensed because there was no Bibliography included. No other source of the study could be found.

Weida Model (1977:8).

Weida found that R&D expenditures follow an S-shaped curve. The study was focused on modifying the curve so it could be used for Cost/Schedule forecasting (47:4). The S-shaped curve is a cumulative form of a bell shaped curve with the inflection point being the mid-point of the bell shaped curve (47:5). The general approach was that each curve (break at inflection point) fits a separate equation.

The one problem is the R&D data have a tendency for autocorrelation which must be eliminated before an equation can be determined (47:6). The 22 programs showed that a quadratic equation or logarithmic equation fit the curves(47:18).

The inflection point is the last largest incremental changes which is followed by two periods of decreasing expenditures. This is the last point of the lower curve and the first point of the upper curve (47:18). Actual cost are used in the equation to project an EAC (47:19). This procedure has the flexibility to produce a worst, best,and most likely EACs and provide confidence intervals (47:21-31). The procedure takes the lower half equation and calculates Y then substitutes Y for the Y in the second equation to determine the y-intercept (a). The y-intercept is placed in the upper half equation so the schedule variance can be determined (100% + Schedule % variance). This value replaces X and the resulting Y value is the percent the BAC is multiplied by. This study did not compare this formula against any other formulas. The following example will illustrate this procedure.

Example:

Lower half equation:

$$Y_1 = .5 - .7(X_1) + .2(X_2)^2 \qquad (63)$$

X_n = 46% complete

$Y_1 = .5 + .7(.46) + .2(.46)^2$

$Y_1 = .86$

Upper half equation:

$$Y_n = .3 + 1.8(X_1) + .1(X_2)^2 \tag{64}$$

$$.86 - 1.8(.46) - .1(.46)^2 = a \text{ (y-intercept)}$$

$$a = .011$$

$$\text{schedule variance} = 1.0 + .01 = 1.01$$

$$Y_n = .011 + 1.8(1.01) + .1(1.01)^2$$

$$EAC = BAC(Y_n) \tag{65}$$

(47:39-40)

Summary

This chapter reviewed the EAC literature and separated the formulas found in the literature into past performance, regression, and other techniques categories. These EAC equations have been compared for accuracy of forecasting related to percent complete, weighting percent, type of contract, and type of product. Other approaches such as Bayesian probability, S-shaped curve, "adaptive" forecasting, and exponential equations (Busse Model) were reviewed. The next chapter will critique each study in order to evaluate the merit of the research conclusions.

III. Analysis of Research Studies

Chapter II reviewed the different EAC models and studies. This chapter will analyze the studies' strengths and weaknesses. The studies in Chapter III are separated into three categories according to the type of EAC formula (Past Performance Factors, Regression,and Other). The Study Type (ST) column of Table 1 further divides the sources into:

1. Comparison Studies
2. Model/Approach
3. Follow-on Studies

Chapter III will be separated according to the categories above. As stated in Chapter II, a "Study" is defined as research that compares different EAC formulas using Cost/Schedule performance data. "Models" present EAC formulas as single equations or a sequence of steps or techniques to produce an EAC. Since Follow-on studies are usually associated with Comparison or Model/Approach studies, they will be discussed with their associated study type. In order to evaluate the studies, evaluation criteria were established.

Evaluation Criteria

In evaluating a study what should you look for? C. William Emory, in his book Business Research Methods, gave seven tests that good research should meet.

> 1. The purpose of the research, or the problem involved should be clearly defined and sharply delineated in terms as unambiguous as possible.

2. The research procedures used should be described in sufficient detail to permit another researcher to repeat the research.

3. The procedural design of the research should be carefully planned to yield results that are as objective as possible.

4. The researcher should report, with complete frankness, flaws in procedural design and estimate their effect upon the findings.

5. Analysis of the data should be sufficiently adequate to reveal its significance; and the methods of analysis used should be appropriate.

6. Conclusions should be confined to those justified by the data of the research and limited to those for which the data provide an adequate basis.

7. Greater confidence in the research is warranted if the researcher is experienced, has a good reputation in research, and is a person of integrity.

(21:10-11)

Table 3 summarizes the evaluation of the studies based on general characteristics of the first six tests in the above list. The seventh test will not be considered since the authors are not known to the researcher and theinfluence could bias the evaluation of the other six tests. The six tests are represented in Table 3 as "Research Clarity", "Documentation", and "Methodology". The numbers are study or model reference numbers from Table 1.

"Research Clarity" involves the structure of the study. If the purpose of the study is clearly stated ("Clear Purpose") and if the importance of the study is described ("Importance") then a "Y" (Yes) is reported in the table; otherwise a "N" (No) is reported. The other Y's and

TABLE 3

ANALYSIS OF EAC MODELS AND STUDIES

Criteria	Model/Approach 1	2	3	5	7	8	10	13	15	19	Comparison 4	6	9	11	12	14	16	17	20
Research Clarity																			
Clear Purpose	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Terms Defined	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Importance	N	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Understandable	N	Y*	Y	Y	N	N	Y	Y	Y	Y	Y*	Y*	Y*	Y	Y	Y	Y	Y	Y
Limitations Stated	Y	Y	Y	Y	Y	N	N/A	Y	N	N	Y	Y	N	Y	Y	N	Y	N	N
Conclusions Stated	Y	Y	Y	Y	Y	N	N/A	Y	N	N	Y	Y	Y	Y	Y	Y*	Y	N	Y
Documentation																			
Data Source Stated	N/A	Y	N/A	N	Y	N	N/A	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Data Included	N/A	Y	N/A	Y	Y	Y	N/A	N	Y	N	N	Y	N	Y	N	Y	N	Y	Y
Calculations	Y	Y*	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	Y	Y
Literature Review	N	N	Y	Y	N	Y	N	N	Y	N	N	Y	Y	Y	Y*	Y	N	Y	N
Reproducable	N/A	Y	N/A	N/A	Y	Y	N/A	N	N	N	N	Y	N	Y	N	Y	N	Y	Y
Methodology																			
Theory Based	N/A	Y	N	Y	N	Y	N	N	N	N	N	N	Y	Y	Y	N	N	N	N
Sample	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Size		N		N/A	N	N		N	Y	N	N	N	N	Y*	Y*	Y	Y	Y	Y*
Representative		Y		Y	Y	Y		N	Y*	N	Y	Y	Y*	Y	Y	Y*	Y	Y*	Y
Method Description	N	Y*	Y	Y	N	Y	N	Y	N	Y*	N	Y*	Y	Y	Y	N	Y	N	Y
Statistics Tested	N/A	N	N/A	N/A	N/A	Y	N/A	N/A	N/A	N/A	N	N/A	N	N/A	N/A	N	N	N	N/A
Literature Source																			
DTIC	Y		Y	Y		Y						Y	Y				Y		
Periodicals								Y		Y				Y@	Y				
Service Libraries		Y			Y		Y		Y		Y	Y	Y		Y	Y	Y	Y	Y

N - No   Y - Yes   N/A - Not Applicable   * - Minor problem   @-Found by contacting contractor

N's similarly report this author's judgment of the reviewed studies relative to the qualitative criteria listed. The study should also employ concise, simple wording ("Understandable"), and define unusual terms or jargon ("Terms Defined"). Conclusions should be clearly stated and be based on the data in the study ("Conclusions Stated"). Finally, representing the conclusions as being universal without expressing the known flaws or limitations of the study can be misleading. Thus, the limitations of the study should be described ("Limitations").

The "Documentation" section looks at the written support of the research. At the very least, the study should report the source of the data ("Data Source Stated"). Ideally, it should also include the data ("Data Included") utilized in the research. "Calculations" in the research help a reviewer to justify the conclusions of the author. In any type of work (sports, teacher, briefings) preparation is required. A "Literature Review" of the subject is the preparation that makes research an addition rather than a repeated study effort that adds nothing. The last criterion in this category is "Reproducability". The documentation should be sufficient to allow the study to be reproduced by another researcher.

Analysis and collection of data can be the most difficult phase of research (21:11). The "Methodology" section is designed to evaluate the adequacy of the studies in this area. The World Book Dictionary defines theory as "the

principles of a science or art rather than its practice" (2:2174). Under this section the "Theory Based " criterion is met when the study evaluates or tests a stated theory rather than explores a database for unknown relationships. The "Sample" criterion was included mainly for the Model studies. This indicates an example is included for illustration or a comparison of formulas. Comparison studies utilize databases. The research methods assume normalcy exists because of the Central Limit Theorem (23:273). If the Central Limit Theorem assumptions are met the sample size ("Size"), as a rule of thumb, should be equal to or greater than 30 (23:275). The reliability of the data ("Representative") is another criterion. This research defines "Representative" as data from a C/SCSC approved system (CPR data or C/SSR data with explanation of system being reviewed). In order to understand the results and the methods of evaluation a complete description of decision criteria, models and formulas, and statistical assumptions must be presented ("Method Description"). "Statistics Tested" refers to evidence that the assumptions were tested if statistical evaluation was performed.

The last section, "Literature Source", describes the availability of the studies. "DTIC" refers to studies located and obtained by the Defense Technical Information Center (DTIC) system. "Periodicals" refers to professional journals or business periodicals. "Service Libraries" are the base or cost libraries located at DOD installations.

The above criteria will answer the six tests stated by Emory for good research. The nomenclature and standards for the evaluation are described below.

The analysis will look at Models/Approaches and then Comparison studies. Computer programs and AFIT courses will not be included. If a criterion is met by a study or model, it is assigned a Yes (Y). If a study or model omits, provides insufficient detail, or misstates a model or procedure it is assigned a No (N). Sometimes decisions are hard to make because of minor flaws that would not warrant a Yes or a No. In this case an * is assigned. Pure model presentations will not be affected by the Sample, Theory Based, or Evaluation Method criteria. Not applicable (N/A) will be assigned to these criterion.

<u>El-Sabban Model (1).</u>

This research did state its purpose but importance was never covered. An example and calculations are supplied but critical steps are missing and explanations are too general. Without an adequate example it is difficult to do the calculations. Limitations were described. One limitation was the assumption of a normal distribution for cost and schedule data (20:7).

The weaknesses of the study are in major areas that represent good research. The study expected a very good understanding of Bayesian probability by the reader. Terms and calculations were not defined or adequately described.

El-Sabban associated the CPR data elements to the formula elements (See page 45 for association) but there was no explanation of why the particular CPR element corresponded to a particular formula element (20:8). No literature review was conducted. The model was not validated. Generally, this research left many questions and unexplained critical elements of the proposed model.

Karsch Model 1974 (2).

Karsch presented a model based upon a nonlinear equation. The terms were defined and the data source, one contract, was identified. The data were provided. There was some theory based (Y*) research (nonlinear relationship of data) but as an aside not as a main point and no elaboration of how many data points were observed to reach the conclusion (28:13). The study also theorized that "completed program samples are similar in their characteristics and $Y = b_1 X^{b2}$ is a reasonable behavioral relationship . . . . that b_1 and b_2 reflect these similarities " (28:4). The similar characteristics that b_1 and b_2 reflect were not stated.

One of the weaknesses of this study is that the conclusions are not supported. Karsch refers to looking at a "variety of samples", and b_2 was found to be "between 1.18 and .97" but there is no supporting details (28:15). Karsch also concludes the model is an improved method. However, the research is based on only one contract so generalizing to other contracts is not justified. The

purpose is implied and the importance of the study is never revealed. According to Neter, some non linear parameters can be transformed to make them linear (37:550-551). There was no evidence that transformation of the nonlinear parameters was attempted. This process seems to be a logical step for this research. No validation of the model or the b_2 was presented.

Holeman Model (3).

This study was very strong in Research Clarity and Documentation. The purpose and importance were straight forward. He viewed the use of EAC formulas as a more flexible model and a check against the contractors' EAC since these estimates were generally optimistic (27:5). Research into other literature on EAC formulas was performed and presented in the Appendix (27:Appendix A). The wording and organization aided in the understanding of the procedures and basis for the models (3). Examples and associated calculations were provided which also helped in understanding the models. Conclusions provided limitations of the technique and of forecasting in general.

In the conclusions Holeman stated that baseline changes greatly affected EACs generated by historical performance indices. This was not debated or tested as part of the research design, but merely referenced as an advantage of the models presented since the models were not solely based on historical indices (27:29-30). This is why a "No" was

given to the "Theory Base" criterion. The experience of the analyst and the amount of input from other SPO experts were limitations to the effectiveness of the model (27:31-32). These models were not validated (use actual program data) in the study or in any other study.

Busse Model (5).

This research developed a model that was based on the theory that a relationship exists between ACWP and BCWP that can be developed into a model (8:22-23). The relationship is for forecasting only since, in reality, more factors than BCWP influence ACWP (8:23). The Research Clarity section was given a Yes for the criteria. One recurring limitation in the model development research is that the model not be used as a sole predictor of EACs. Busse clearly warns the user against the sole use of his model (8:5). Data form only one contract were included for illustration purposes. Accordingly, "Sample", "Representative", and "Data Included" are marked "Yes" and "Size" marked "No". N/A was assigned to the "Reproducible" criterion because there was no comparison of formulas or validation of the model.

Heydinger (SAMSO) Study (7).

The SAMSO was a study that presented a modified model and was also a comparative study. One of the few strengths of this study is that no conclusions were made about the SAMSO model. This seems like a strange statement, but this study had limitations in its design and to formulate any

conclusions about the SAMSO model based on this study would have degraded the integrity of the study (26:33). The comparison and demonstration was done using one data program which is not adequate to draw conclusions about model comparison. The data were provided and the comparison can be reproduced. The study refers to historical data evaluation but does not reveal the number of contracts used.

Explanation of evaluation methods and supporting documentation were strong weaknesses. The statement was made that "SAMSO data analyzed to date shows the same similarity with b_1 falling between 1.18 and .97" but no data was provided to support the statement (26:6). This statement is incorrect because it is b_2 not b_1 that falls in the range (28:15). The misstatements and lack of explanation and literature support of equations gives the appearance of personal opinion and hurried research. Lack of explanation of "closest to final cost" for picking the formula is just one example (26:10-11).

Wieda Model (8).

The description of the procedure and basic explanation of the approach is hard to follow. Regression analysis was used and statistical problems like autocorrelation and heteroscedasticity were checked for and resolved as much as possible (47:7-9). A sample of 22 R&D contracts is considered too small to generalize to all R&D contracts.

The study is reproducible because the programs are listed and a little research will produce the data (47:56). No conclusions were presented, just a model. No limitations were mentioned in the study.

Lollar Model (10).

Lollar's model was a project that presented a different technique with no justification or explanation. This project presented a model only. The "Purpose", "Define Terms", "Importance", and "Calculations" were all stated but the research did not continue past this point.

The "Conventional Model" was confusing because it appears as if the formula is a weighted index formula but later in the explanation it is BAC / CPI (32:11a). There was no evidence of a literature review to see if this procedure had already been developed. There was no supporting explanation of how he developed the weighting procedure or the logic behind the procedure. Taking the absolute value ignores the direction and effect of the variances. The absolute value treats the variances as all positive when in reality there may be a negative variance or both variances could be negative.

The mathematical procedure (taking absolute value) does not appear to be a viable way to determine a weight percent for the performance factor. This formula was validated in Blythes' 1982 comparison study. The comparison resulted in recommendation for discontinued use of the model (6:8).

Chacko Approach (13).

The method is internal to the MESGRO computer program. The approach works on the theory that instead of fitting the data to a model the opposite is done (9:75). The study was understandable, limitations were stated, conclusions supported by the data presented, and terms were defined. There are limitations in that it predicts well in the short-term but only predicts the direction of the change in the long run (9:95).

Although the study is strong in the Research Clarity area, it is weak in the Documentation and Methodology areas. It did use a database, but no indication of the source of the database, the calculations, or the data type were provided. Thus, it is not reproducible. The approach uses a computer program called MESGRO so calculations were not supplied (9:81). Without seeing the internal calculations it is very hard to give any confidence to the methodology. No formulas are available for this approach.

Blythe 1984 Study (15).

No indication is made to the importance of developing this formula (5:2). The study was understandable and the sample size (26 programs) adequate, considering the population and focus of the research (5:3). There is also reference to C/SSR data being used. However, no evidence is provided regarding its reliability.

Since the "adjustment factor" was designed for the 26 program mix, the forecasts limitation should be the dollar range of the programs. This limitation is not addressed and the implication in the study is that the factor can be used universally. A set of different programs was not used to validate the model.

Appendix A of Lollar's report was lost in the library system. This section may have contained detailed calculations and an explanation of procedures. Accordingly, a "No" rating is given for the "Understanding", "Calculations", and "Reproducible" criteria. "Data Source Stated" and "Data Included" criteria are each given a "Y" because they are included in his referenced 1982 study and were used to establish the adjustment. There has been no validation of this formula.

Totaro Model (19).

The Totaro approach was one of the few reports published in a periodical. It had a clearly stated purpose. Definitions and the "Importance" were also revealed. Calculations and examples were provided so manipulation and understanding the working of the formula was easy. This study used six contracts for a comparison with the best formula of Prices' study. Numerical results or conclusions from the comparison were not stated; just obvious generalities (45:33).

The source of the data was stated but the program names were not included so Sample and Reproducible criteria were assigned "Ns". Description of the procedure was good but justification of his linear relationship of SPI and CPI to percent complete was not given (Y* in Description). There was no evidence of any review of literature to support his assumptions or theories. This method did not include a sample size sufficient for validation.

Model/Approach Summary

This analysis concentrated on studies that were developed or modified models and new approaches. Some criteria were considered not applicable to the study because the study presented a model only with not comparison to other models or examples. The next section will review comparison studies which have as their major focus the comparison of different models.

Analysis of Comparison Studies

The following studies compare different models in order to select the most accurate predicting model of final cost. Some studies present new models along with the comparison. Some of the methodologies used in the research did not use regression analysis or any statistical evaluation as a part of the decision criteria. If this is the case, "Statistics Tested" criterion will be assigned a Not Applicable (N/A) rating. The same evaluation terminology (Yes and No) applies to these studies.

Karsch (1976) Study (4).

The study was a sequel to his study done in 1974 with the definitions and explanations referenced to that study. The exception is Purpose and Importance which were addressed in this study. Calculations for a missile and aircraft program were supplied.

The evaluation criteria for closest to the final cost is still not explained (N for Description). Results were mentioned in the study with no support or literature review supporting the formula or assumptions. Data for one sample of aircraft and missile were included but the source of the rest of the data was not included. There was no indication of aircraft or missile number but sample size is very small for conclusions of b_1 value ranges. Since the formula was nonlinear, no testing was done to see if transposing would produce a linear relationship (N Test Statistical Assumptions).

Hayes Study (6).

This was a follow-on study of Bayesian probability done by El-Sabban. Research Clarity and Documentation were strong points. Purpose, Importance, and Definition of Terms met the criteria, but in order to understand and follow the study a thorough knowledge in Bayesian probability was needed (Y* for Understandable). The same limitations as to assumptions as El-Sabban were recognized. The conclusions

were supported with adequate explanations. The Documentation was available to reproduce the study.

The major problem is the sample size (5). Statistical assumption testing was not applicable (N/A) because the evaluation criteria were based on what estimate was closest to the final cost (25:44).

Land and Preston Study (9).

This study did look at or add to EAC theory as it applies to linear and nonlinear equations and to the theory that Karschs' growth exponents (b_1 and b_2) reflect the characteristics of the program (aircraft) by exhibiting a narrow range (30:10). This program did use completed programs but the explanations and organization made the study hard to follow at a few points.

The weaknesses of this study are in the Documentation and Sample criteria. The sample consists of 30 contracts with 20 being aircraft programs. A sample of 30 contracts is an adequate sample for the first part of the study that evaluated the ESD models, but when the ESD and Karsch models are evaluated only 20 aircraft programs are considered (30:50). The population was defined as "all DOD procurement programs which require contractor submittal of either a Cost/Schedule Status Report (C/SSR) or Cost Performance Report (CPR)" (30:19-20). Since the database is not included and the aircraft names are unknown, the data are suspected to be Air Force only since ASD Contract Library

was the source of the data (30:21). By using C/SSR data, which does not require a C/SCSC validated system, the reliability of the data now comes into question and affects the Representative criterion.

The documentation is very poor with this study. Land and Preston transformed the Karsch model by the use of logarithms. Karsch calls his model a nonlinear model. If this is truly a non linear relationship then transforming the parameters will not give you a linear relationship (37:551). There is no scatterplot provided that demonstrates this transformation is linear (30:29). The absence of the database makes the study not reproducible. No limitations were provided. The results imply that they can be used universally, but in fact the database was limited to Air Force programs.

Covach (NAVSEA) Study (11).

This study satisfied all the evaluation criteria. Except for size of data base, it is given a solid Yes (Y). This study dealt with NAVAIR contacts only so the population was small to begin with (16). Six programs were used in evaluating the formulas. As compared to the population, the six programs are a significant percent of the population (Y*). This was noticed as a limitation of the study (Hayson:3). The other programs were used in the manpower evaluation (12:55). Regression and Past Performance Factors were not compared to each other.

The extension study (Haydon) was not evaluated in Table 3 because it is presented as added information. The second report did not use the same nomenclature as the original study. CPI was defined in the original study as ACWP/BCWP and in the extended report it is defined as BCWP/ACWP (24:5). Equations are restated using this relationship so accuracy is not affected. A different method was presented for calculating the EAC using a range approach. The "EAC Range" is not defined as to the formula used to calculate the EACs (24:8-12).

Bright and Howard Study (12).

Research Clarity was a strong area in the study (all Yes). The purpose was to compare formulas that are provided in a computer program so managers could pick formulas to use that were better for different percent completion points of a contract (7:1-3). Terms and limitations were explained and conclusions were supported by the data (7:18). The new model was based on the theory that "CPI must be deflated when behind schedule and inflated when ahead " (7:17). CPI x SPI represents this relationship (7:17).

The weak area of the study was in Documentation. The data source was indicated but the programs. The data were not included and the calculations to support the CPI_6 x SPI_{Cum} combination was not provided (7:8). There was a review of literature as indicated in the bibliography, but very little citation of the sources in the text (Y* rating).

Looking at Army R&D contracts as the population the sample size of 11 could be significant (Y*). The study is limited to Army contracts.

Blythe (1982) Study (14).

This is one of the studies cited by Wallender to justify the AFSC weights. This study used 26 programs which included missiles, engines, guns, armament, and aircraft (6: Appendix A). It did not evaluate by contract or production item type, so sample size is adequate considering the population of ASD contracts with CPR or C/SSR requirements. The criterion of Representative was based primarily on the reliability of data. Since the C/SSR does not require a validated C/SCSC system, the C/SSR data are suspect. Because this study included C/SSRs it is rated Y*. The Purpose of the study was to validate a model that was being used by analysts and ASD. This study was reproduced by Cryer and Balthazer.

This study was strictly a comparison of EAC formulas. No new EAC formulas were presented. No new theory was proposed. It looked at different percent completion points and evaluated models using percent accuracy and standard deviation. The conclusions imply a generalization to any contract, but this is risky since the sample had few contracts of different types. There were no limitations stated in the study. Regression assumptions were not tested or stated.

A separate part of the study looked at the different weighing % that could be used with the Parker Model. The weighing evaluation was based on the lowest Coefficient of Variation (CV) (6:5). There were no calculations in the appendix to support the conclusions presented in this area (Y* for Conclusions).

Price Study (16).

Prices' Master Thesis is a purely comparative study. Price states his purpose of evaluating the six EAC techniques is to find a the most accurately predicting formula within the CPRA analysis program (40:3,13). The conclusions do relate to the data results and the limitations of the study were state.

Weaknesses of this study are in the Documentation and Methodology sections. There was no indication of any type of literature review except for quotes from one past study. The Price study can not be reproduced because the program data or names used in the database are not included. The assumptions for regression analysis were tested but no example of data calculations to support the linearity assumptions, normality, and homoscedasticity are provided (40:20-21).

One of the weaknesses in the Methodology section was the treatment of contracts with different percent completions as if they are finished programs at that percent. No completed programs were used. The last CPR BCWP was set as the BAC

and the ACWP was set as the final cost at any % complete point (40:17). This assumes a linear relationship throughout the contract at all stages which would give a worst case estimate in the beginning of a contract.

Wallender Paper (18).

The paper by Wallender (20) was a justification of the "HQ AFSC EAC" formula. The three studies that justified the formula are helpful as sources of EAC formulas and results. Of the three, only one study could be found, the ASD Reserve Study. Wallenders' paper is omitted from Table 3 because it is not a study. In reading the summary of the HQ AFSC Study, the methodology was to compare an estimate to an estimate (46:2). Without more details this method seems to evaluate how close the formula is to another estimate, not the final cost.

The AD Study compares final contract cost to the EAC from the AFSC formula, but then compares the OSD EAC and AFSC EAC. The OSD EAC was found to be 10-12% higher than the AFSC EAC but there is no indication as to how the OSD EAC formula compared to final costs.

Balthazer and Cryer Study (17).

The study is a reproduction of the previous study and contains the calculation which can be used to verify results (13:Appendix). The study is a replication of Blythes' 1982 study so ratings and reasons for Sample and Evaluation

Method are the same. The study looks at practice rather than theory.

Weaknesses include Conclusions and Limitations criteria. The findings and recommendations are hard to interpret since no evaluation criteria were stated. The weightings of .1 and .9 as well as the .2 and .8 percentages were very close according to the coefficient of variation (CV). Conclusions state the weights of .4 and .6 had the lowest standard deviation, a point that had no significance since the evaluation criterion is lowest CV. Regression analysis was used, but no assumption testing was performed or presented. The Lollar model was also stated incorrectly. In the Cryer and Balthazer study, the model was written as the Schedule and Cost variance factor multiplied by the absolute value of the Schedule or Cost performance index which is incorrect. The SVf and CVf were also calculated incorrectly because the absolute value of SVP and CVP are added together for a total percent then the SVP or CVP are divided by the total (13:3). From the calculations it appears this formula was miscalculated which could change the comparison results but not the weighting combination comparison.

Reidel and Chance Study (20).

This is one of the most recent comparative EAC study. Formulas were evaluated according to different percent completion points, contract types, and end item types. The study is reproducible, understandable, and includes

calculations and explanations of all data sources (41:A-1 - A-15).

The definition of EAC 7 is not comparable to the actual formulas referenced (41:5-5,12-13). The Totaro model does use percent complete for determining a weighting factor but not as stated in this study. The SPI weighting is determined by the weight decided by the analyst then reduced by a factor based on percent complete. The CPI weighting is increased in the same manner.

Totaro factors:

Wght SPI = .25-[.25(%complete)SPI] (66)

Wght CPI = .75+[.25(%complete)CPI] (67)

Example: 30% complete

.25-[.25(30%)SPI] = .25-7.5 = .175

.75+[.25(30%)CPI] = .75+7.5 = .825

(45:31)

Reidel Study EAC 7:

x = % complete = 30%

x (CPI) + (1-x) SPI = .3CPI + .7SPI (67)

Because these methods are not the same, the "Terms Defined" criterion is awarded a No (N).

The study did not use citations. No limitations were stated but the DSMC course material formulas came from the NAVSEA study. The NAVSEA study has a limitation in the fact that the database used to evaluate the formulas are Navy programs only (12:5). The sample size is small for each contract type and end item but could be appropriate

considering the population is ASD contracts (Y*). The methodology uses "Average Absolute Value Deviation" method as the primary evaluation criterion and "Average Rank Order" as a check (12:18-19). No statistical assumptions needed to be tested (N/A).

Summary

This chapter reviewed the actual studies by categories of model and comparison studies. The studies were evaluated on clarity, documentation, and methodology. Results of the analysis will help evaluate the study results based upon the strengths and weaknesses of the studies. The next chapter will review the objectives of this research and provide recommendations for future research.

IV. Conclusions and Recommendations

The A-12 Program, tighter DOD budgets, increased oversight by Congress and DOD, and the reduction in manpower are bringing the role and use of EAC formulas to a heighten level. Program and Financial managers, as well as, CPR and C/SSR analysts will not be able to ignore the estimates generated by the EAC formulas. The increased attention EAC formulas will achieve in the future will increase the research into this area. Because of this, knowing what has been accomplished is essential.

In Chapter I the four objectives of this research were proposed in order to accomplish the above. The conclusions will be structured around these objectives.

First Objective: Identify and Collection

In order to establish any research base the researcher must know where to look for the literature. When this research was started, it was a belief that very little research had been done in the EAC area. This belief was soon disproved because 24 different sources were found. Finding these studies was not easy.

Most of the sources were obtained through the Defense Technical Information Center (DTIC) system or at the Aeronautical System Division (ASD) Cost Library at Wright-Patterson AFB. Talking to people in the C/S area and searching the bibliographies of obtained research was the main technique used for the search. The belief of this

researcher is that more EAC studies are buried in libraries at Navy and Army installations. Any research should involve a review of the libraries along with the DTIC and bibliography searches.

It is obvious that the dissemination of this knowledge to the field is very limited and unpublished. Only two of the studies were found in professional journals or publications. No wonder Program and Financial managers, as well as the C/S analysts, are not aware of the different types of EAC formulas and give little confidence to the results from EAC formulas.

<u>Second Objective: Categorization and Summarization</u>

This objective starts the foundation building of the EAC research. The research studies start in 1973 and focusedthe on model development until 1977. A few studies during this period did comparisons but a new approach or model was usually presented. These authors were the pioneers in the EAC area. The focus during this time period was on model building and new approaches.

From 1980 to 1986, Blythe, Lollar, Cryer and Balthazer, and Wallender focused on the best combination of percentages for weighting indices. Lollar's formula was used for a period of two years or longer at ASD before Blythe's study showed that it should be replaced. The perception is that EAC work before Lollar was not critically analyzed but just accepted. During this time period, the trend changed from

model development to evaluating the forecasting ability of the EAC formulas.

In the last five to six years the emphasis has been on the comparison of EAC formulas. The studies focused on Index type formulas and usually involved the same group of formulas. Regression models have been reviewed but little work has been done on this category in the last 10 years. There have been many other approaches such as Time Series, Bayesian probability, S-Curve, logic formulas, and exponential relationships that have been developed but little work has been done to expand upon or validate these models or approaches. This may leave the analyst and other interested personnel with the belief that there are only a handful (4-5) of formulas that can be used to generate an EAC. In reality, there are an infinite number of EAC formulas. Appendix C shows 43 EAC formulas reviewed in this thesis.

Third Objective: Analysis of Studies

In order for managers to have confidence in the EAC formulas the research itself must be done in a convincing manner to instill confidence in the results. Of the 19 studies analyzed in Table 3, the following weaknesses were identified:

1. Limitations not stated
2. Documentation inadequate
    - A. Calculations missing

B. Data not included

C. Size of sample

D. Description of Data

E. Reproducability

3. Methodology defective

A. Statistical parameters used

B. Proof

4. Literature review deficient/absent

5. Lack of theory based studies

The "Limitations" of a study are critical to how the results are applied. One of the major limitations was that results applied to a certain database (Army, Navy, Air Force) were being generalized to a broader population. A cost analyst generalizing results to an Air Force program that was generated from a Navy database would have a tough time justifying the EAC formula or the estimate.

"Documentation" was the weakest category. The major problem was reproducability. Having a study that can be reproduced (results and procedures) by other researchers adds validity to the conclusions and future work of that researcher. Missing calculations to support results, databases that were considered to small to be representative, and description of why the data used were accurate and reliable were areas that also contributed to poor documentation. Not including or identifying the data sources or contracts used makes it impossible to reproduce a study.

Another area that goes along with documentation was the lack of methodology description. Some studies did not explain the decision criteria for all the results presented. In the earlier studies (1973-1981), statistical procedures (regression analysis, standard deviation, coefficient of variation) were used without any explanation of "why". In some cases the "why" would be explained but proof (scatterplots, graphs, calculations) of the conclusions of the tested assumptions was not supplied.

One area of surprise was the lack of a literature review. Of the 19 studies, nine had no bibliography, or review of prior studies, or citations to support the data used. This supports the idea that research in the EAC area is undisciplied and lacks direction. Theory based EAC research was found to be rare.

It is not concluded that the EAC research lacks merit. But for the research to be accepted by practitioners and managers, it must be able to withstand a critical review. Confidence in results and solid research that can be used for justification by an analyst or manager is a must for EAC formulas to be actively considered and used.

Fourth Objective: Study Results

What can be gleaned form all of this research? One "sacred" EAC formula was that .2 SPI and .8 CPI was the best combination of weighted indices. When an analysis of the Blythe and Cryer was done, this long standing standard

becomes a little shaky. The weaknesses and strengths in the studies lead to the conclusion that .1 SPI and .9 CPI, .2 SPI and .8 CPI, and .3 SPI and .7 CPI are combinations that yield equally accurate EACs.

Managers (program and financial) usually review the contractor's EAC with skepticism. However, the early literature showed this EAC to be the most consistent and accurate. Blythe showed this in his study and developed an EAC formula that utilizes the contractor's EAC. One result that all the researchers agreed with was that more than one EAC formula should be used to develop an EAC and the possibility of using the contractor's EAC could be one of the methods.

When the different types (Past Performance Factors (PPF) and Regression) of formulas are reviewed the area of least emphasis has been in the regression area. Bright and Howard did some work with two regression models in comparing them with PPF type formulas and found that up to 30% complete the regression formulas did well at predicting final cost. The NAVSEA study reviewed a number of regression models but evaluated them against each other not against PPF type formulas. This is still a wide open area for research.

An analyst usually uses a PPF type of formula. The work in this area has compared formulas by certain completion points, by type of contract, and by product type. Each study showed different formulas depending upon the group of formulas used. The largest group of formulas was done in

the NAVSEA study. An analyst must evaluate the program and the study's limitations and pick the EAC formulas that are appropriate. The results and formula rankings are presented in Chapter 2.

One of the formulas that is referenced when C/S people talk about EAC formulas is the Howard Model (SPI x CPI). Most of the presentations seen by this author show this formula erroneously. The model was originally established to be the Cum SPI multiplied by a six month moving average CPI.

<u>Summary</u>

The review of the studies showed that some rules of thumb are not supported by the literature. The weighting of indices is still a wide open area. Regression analysis is an area of limited research. The Karsch model shows promise but the B_2 value must be narrowed down for product type and contract type. The past performance index models have some good results, but the limitations of the studies need to be described by the researcher and considered by the analyst when doing research or selecting an EAC formula.

The data relationship is another area that needs to be cleared up. Most studies have assumed linearity. Weida and Karsch showed Cost/Schedule data to be nonlinear. This is a basic characteristic that needs to be resolved.

Another area of weakness is theory based EAC research. There seems to be no consideration of "why" models predict the way they do.

Recommendations for Future Studies

Instead of evaluating formulas by contract type or product, maybe the formulas should be compared by contractors. Contractors in the defense industry have different management styles which may be reflected in the C/S data. An evaluation by contractor may show different formulas are best for different contractors.

Another area is the databases used. If results are to be applied on a universal level, the formulas should be evaluated using a DOD database such as the DAES report. This database was used by Scot Heise in a Masters Thesis in 1991 at AFIT and is available through his advisor, Major David Christensen AFIT/LSY. Another area that goes along with the database is the testing of larger groups of formulas, such as the NAVSEA study. The studies should include unvalidated models and regression models.

Some of the models such as the Bayesian approach, Busse Model, Holeman Models, and Weida Model can be very complicated. The computer knowledge and ability that is currently available in programming, could be used to develop the above models so that an analyst only inputs CPR data and gets an EAC back.

Theory should be developed and tested. Payne looked at CPI stability in a 1990 AFIT thesis. What about SPI stability and influence?

Appendix A: Explanation of Cost/Schedule Control Systems Criteria (C/SCSC).

Cost/Schedule Control Systems Criteria (C/SCSC)

C/SCSC is not a management system imposed upon the contractor, but a set of standards that the government uses to evaluate the management system of the contractor (16:V). The criteria provide a set of minimum standards that a contractor's management control systems must comply with. Organization, Planning and Budgeting, Accounting, Analysis, Revision and Access to data are the areas the Criteria address (16:2-1, 2-3). A checklist of questions is used to evaluate if the contractors management system complies to the criteria (16:E-1, E-16). After a successful demonstration, the management system should provide data which:

1. Indicate work progress;
2. Properly relate cost, schedule and technical accomplishment;
3. Are valid, timely, and auditable;
4. Supply managers with information at a practical level of summarization.

(18:5)

In order to maintain confidence that the management system is operating as demonstrated, periodic surveillance of the system is required. Representatives from the Defense Logistics Agency (DLA), the Contract Administration Office and the Program Office visit the contractor to make sure the

system is still operating as it was validated and to look at problem areas that appear in the CPR or C/SSR reports (17:1).

Not all major contracts are obligated to have C/SCSC. Prime contractors that receive contracts over $60M for Research and Development, or over $250M for Production are required to conform to C/SCSC. Subcontractors are also required to have their management system compliant to C/SCSC if the subcontract is determined to be critical by the government and the contractor. (The exception is a Firm Fixed Priced (FFP) contract) (19:11-B-2 11-B-4). If the contractor's management control system is C/SCSC compliant, then the performance data generated by that system is assumed to be reliable. The data are summarized in either the CPR or C/SSR.

The data are accumulated at the end of each month and transmitted to the government on a Cost Performance Report (CPR) or a Cost/Schedule Status Report (C/SSR). C/SSR reports are usually for contracts that do not require a CPR, are over $5 million, and are at least one year in length. C/SSR reporting does not require a system that is C/SCSC compliant (15:1).

The CPR has five formats and the C/SSR has two formats. The formats are described below:

CPR

Format 1: The contract is structured by different product items or segments of work. Each product item or

segment requires a group of tasks be completed. This is called a Work Breakdown Structure (WBS) and is similar to a pyramid with the top being the product (airplane, gun, missile). Each iteration is termed a level which is numbered from the top to the bottom. Format 1 reports current and cumulative costs by the WBS structure and usually limits the structure to level 3.

The heading shows contract information such as contract price, estimated price, authorized but yet unpriced work (estimated) and other contract related elements. There are columns that show variances for the cost and schedule portions as well as a column for the contractors Estimate-at-Completion. Management Reserve, Undistributed Budgets, reprogramming actions, and total contract variances are also shown on this format.

Format 2: This format is similar to Format 1 except that the cost breakdown is by functional categories such as engineering, quality assurance and material. Cost and Schedule Variances, Estimate-at-Completion, and Management Reserve are also shown on this format.

Format 3· This is the baseline format. It shows the time phased dollar amounts for the contract life at the total contract level. Changes to the baseline are listed and explained with the bottom line showing the new baseline dollars and new time phasing.

Format 4: The manpower for the program is time phased by functional area for the next six months and for the rest of

the program by an increment determined during contract negotiations. The actual manpower for the reported month is presented as well as the cumulative amount.

Format 5: Significant cost and schedule variances are explained on this format. There are usually certain thresholds set for reporting on the format. Corrective action, areas affected by the problems, correction plans, and dates are provided for functional and WBS areas that break the contract threshold.

C/SSR

Format 1: The format shows the cumulative cost by WBS element and at total contract level. Contract data such as cost, negotiated changes and estimated cost of unpriced work are shown in the heading. Except for reprogramming actions, all other elements are the same as on the CPR Format 1.

Format 2: Explanation of the problems and analysis of what can be done about them is the major function of this format. This is similar to Format 5 in the CPR and can be triggered by a threshold amount (% variance, dollar amount or both).

The data elements included in the CPR and C/SSR formats are names unique to the C/SCSC arena. EAC formulas utilize these elements and names.

Budgeted Cost of Work Scheduled (BCWS) or "planned value" is the beginning budget allocated to tasks in the WBS. This allocation is done at the beginning of the contact or effort. This is the starting point or baseline from which

performance is evaluated. The budgets are allocated over the life of the contract and can be detailed planned or kept as a lump sum (planning package) until the start date of the work gets closer.

Budgeted Cost of Work Performed (BCWP) is often referred to as "Earned Value". Earned Value is the evaluated amount of work completed compared to what was scheduled (BCWS). Different methods for evaluating the amount of work accomplished can be used but they must be similar to the methods used to plan BCWS.

Actual Cost of Work Performed (ACWP) refers to the work performed (BCWP) not the work scheduled (BCWS). The actual direct costs (labor,parts,material) and indirect costs (overhead) are represented by this term.

Management Reserve (MR) is usually a percentage withheld from the contract total. This amount is for unexpected events. The program manager controls this budget and gives approval for its use.

Budget at Completion (BAC) is the budget allocated to the contract excluding Management Reserve and profit. As contractual changes take place this amount will change.

There are two frequently used ratios in the evaluation of the contractors' performance and in the EAC formulas. These ratios are called Cost Performance Index (CPI) and Schedule Performance Index (SPI).

The CPI is the ratio of BCWP/ACWP. This is called an efficiency CPI and can be interpreted as the dollar amount

of work done for eacn dollar spent. The calculation can be done for current, cumulative, and average data. Another CPI, called a performance CPI, is the inverse of the efficiency CPI. The efficiency CPI is the ratio used in EAC formulas and will be referred to as the CPI in this study. A CPI with a value under 1.0 indicates a cost overrun on the contract. A CPI above 1.0 indicates a cost underrun.

The SPI is calculated by BCWP/BCWS. The status of the schedule is represented by this index. An index less than 1.0 indicates the contract is behind schedule and above 1.0 indicates an ahead of schedule situation. This index can be calculated using current, cumulative, and average data.

Appendix B: Formulas

Indices

Efficiency CPI:	BCWP/ACWP
Performance CPI (CPI_p):	ACWP/BCWP
SPI:	BCWP/BCWS

The indices can be used with current or cumulative data.

Schedule and Cost Variances

Schedule Variance:	SV = BCWP - BCWS
Schedule Variance Index (SVI):	SV/BCWS
% Schedule Variance:	SV/BCWS x 100%
Cost Variance:	CV = BCWP - ACWP
Cost Variance Index (CVI):	CV/BCWP
% Cost Variance:	CV/BCWP x 100%

General Terms

Contract Budget Base (CBB):

CBB = Negotiated Contract + Estimated Unpriced Work

CBB = BAC + MR

BAC excludes MR

BAC = Performance Baseline

BAC - $BCWP_{cum}$ = BCWR (Budgeted Cost of Work Remaining)

% Complete = $BCWP_{cum}$ /BAC x 100%

Moving Averages

$CPI_3 = (CPI_m + CPI_{m-1} + CPI_{m-2}) / 3$ (Average of Ratios)

m = monthly data

$\overline{CPI}_3 = (BCWP_m + BCWP_{m-1} + BCWP_{m-2})/(ACWP_m + ACWP_{m-1} + ACWP_{m-2})$

(Ratio of Sums for Efficiency CPI)

$\overline{CPI}_{P3} = (ACWP_m + ACWP_{m-1} + ACWP_{m-2}) / (BCWP_m + BCWP_{m-1} + BCWP_{m-2})$

(Ratio of Sums for Performance CPI)

$CPI_3 * = (BCWP_n - BCWP_{n-3}) / (ACWP_n - ACWP_{n-3})$

n = Cumulative Month Data

Regression Curve Formulas

$Y = a + bX$ (Linear Curve)

$Y = aX^{b}$ (Power Curve)

$Y = ae^{b(X)}$ (Exponential Curve)

$LnY = a + b \, Ln \, X$ (Log Curve)

$Y = a + bX + cX^2$ (Quadratic Curve)

Appendix C: EAC Formulas

All data elements are cumulative unless stated in the formula. Cur = Current month data

Cost Performance Report Analysis (CPRA) Program

$EAC1 = ACWP + (BAC-BCWP)/CPI_{E\ cur}$

$EAC2 = ACWP + (BAC-BCWP)/CPI_E$

$EAC3 = ACWP + (BAC-BCWP)/CPI_3$ * (See Appemdix B)

$EAC4 = ACWP + ETC$

$ETC = [100-(\text{Cost Var. \%})+.75(\text{Schedule Var. \%})] \times BCWR/100$

$EAC5 = EACC + ETCS$

$EACC = (.12 \times EAC1) + (.64 \times EAC2) + (.24 \times EAC3)$

$ETCS = (\text{months behind Schedule}) \times \text{ACWP Rate} \times .75$

$\text{ACWP Rate} = \text{ACWP/Total contract completed months}$

(40:10-12)

HQ AFSC Formula

$EAC6 = ACWP + (BAC-BCWP)/ (.2SPI + .8CPI)$

(46:1)

OSD Formula

$EAC7 = ACWP + (BAC-BCWP)/ (CPI)(SPI)$

(46:3)

Electonic System Division (ESD) Financial Analysis Program

General formula EAC = ACWP + ETC

EAC8 $ETC = (1 - CVI_{Cur})BCWR$

(30:23)

EAC9 $ETC = [1 - (CVI_{m} + CVI_{m-1} + CVI_{m-2}/3)]BCWR$

m = current monthly data

(30:25)

EAC10 Performance Factor determined by analyst

(1:A2-5)

EAC11 $ETC = (1 - CVI)BCWR$

(30:26)

EAC12 $ETC = (1 - (BCWP_{3} - ACWP_{3})/BCWP_{3})BCWR$

$BCWP_{3} = BCWP_{Cur} + BCWP_{Cur-1} + BCWP_{Cur-2}$

$ACWP_{3} = ACWP_{Cur} + ACWP_{Cur-1} + BCWP_{Cur-2}$

(30:26-27)

EAC13 $ETC = [1 - CVW(CVI) + SVW(SVI)]BCWR$

CVW = Cost Var. Weight

SVW = Schedule Var. Weight

(1:A2-6)

Lollar "Conventional Model"

EAC14 = BAC/CPI

(32:11a)

Lollar Formula

EAC15 = ACWP + (BAC-BCWP)/[SVf(SPI) + CVf(CPI)]

|SV%| + |CV%| = Total%

SV%/Total = SVf

CV%/Total = CVf

(32:11)

Parkers Formula

EAC16 = ACWP + (BAC-BCWP)/(.3SPI + .7CPI)

This type of weighing can produce 11 different combinations by changing by .1 increments.

(13:3)

NAVSEA Formulas (Covach Study)

EAC17 = ACWP + $CPI_{P\,Cur}$(BCWR)

EAC18 = ACWP + CPI_{P3}(BCWR)

EAC19 = ACWP + CPI_{P6}(BCWR)

EAC20 = ACWP + CPI_{P12}(BCWR)

EAC21 = ACWP + CPI_{P}(BCWR)

EAC22 = ACWP + (CPI_{P}/SPI)BCWR

EAC23 = CPI_{P3}(BAC)

EAC24 = BAC/SPI

EAC25 = $\overline{CPI}_{P3}$(BAC)

EAC26 = $\overline{CPI}_{P3}$(BCWR) + ACWP

EAC27 = $\overline{CPI}_{P6}$(BAC)

EAC28 = $\overline{CPI}_{P6}$(BCWR) + ACWP

(12:23-24)

Holeman Formula and Approach

EAC29 = ACWP + BCWR(PPF) +Contract changes + Sch.variations

PPF = Inflation % + CPI(100%) + Overhead change %/100%

(27:22)

EAC30 = Range Method

(27:23-28)

Totaro Formula

EAC31 = ACWP + (BAC-BCWP)/PF

PF = [.25*-.25(BCWP/BAC)]SPI + [.75*+.25(BCWP/BAC)]CPI

*Determined by analyst

(45:31)

Busse Formula

$EAC32 = \bar{Z}(BAC)^{e^*}$

$e^* = (ACWP_{Cur}/ACWP) / (BCWP_{Cur}/BCWP)$

$\bar{Z} = ACWP/(BCWP)^{e^*}$

(8:24-27)

Automated Contractor Performance Measurement System (Army)

General formula EAC = ACWP + (BAC-BCWP)P

EAC33 $P = 1 / \overline{CPI}_3$

EAC34 $P = 1 / \overline{CPI}_6$

EAC35 $P = 1 / \overline{CPI}_{12}$

EAC36 P = 1 /CPI

EAC37 P = Determined by analyst

P = 1/A

$A = [W_1(SPI) + W_2(CPI)]/W_1 + W_2 \qquad W_1 + W_2 = 100\%$

EAC38 $W_1 = .5$ $W_2 = .5$

EAC39 $W_1 = .75$ $W_2 = .25$

EAC40 $W_1 = 1.0$ $W_2 = 0.0$ same as P =1/SPI

REAC2 (See Regression section this appendix)

REAC4 (See Regression section this appendix)

(7:4-7)

Howard Formula

EAC41 = ACWP + (BAC-BCWP)/P

$P = (CPI_6)(SPI)$

(7:17)

Performance Analyzer

EAC42 = ACWP + ETC

$ETC = [1 - (CVI_m + CVI_{m-1} + CVI_{m-2} + CVI_{m-3} + CVI_{m-4} + CVI_{m-5} / 6)]BCWR$

EAC9,11,13

REAC1 (See Regression section this appendix)

(42:86-88)

Olsen Paper

Trend Extension

EAC43 = D/I Ratio (SPO Direct Cost EAC)

D/I Ratio = Contractor Direct Cost EAC/Contractor Indirect and G&A

SPO Direct Cost EAC = SPO Direct Cost ETC + ACWP

SPO Direct Cost ETC = AETC + .75(Schedule Var.*)

*Labor intensive functions only

AETC = Contractor ETC/ (SPI)(CPI)

Contractor ETC = Contractor EAC - ACWP

(38:12)

El-Sabban Study

Bayesean Probability

$$E(\mu) = c\ \mu_a\ \sigma_o^2 + \mu_o\ c^2\ \sigma_a^2\ /\ \sigma_o^2 + c^2\ \sigma_a^2$$

$$V(\mu) = c^2\ \sigma_o^2\ \sigma_a^2\ /\ \sigma_o^2 + c^2\ \sigma_a^2 \qquad \text{(Variance)}$$

$$\sigma = (V)^{.5} \qquad \text{(Standard Deviation)}$$

μ_a = ACWP

μ_o = BAC

$c = \mu_o$ / BCWP

$\sigma_a = .1\ \mu_a$

$\sigma_o = .05\ \mu_o$

(20:6-8)

Regression Analysis (REAC)

REAC1 ACWP is regressed against BCWP by least-squares-best-fit to establish a trend line. The point of the ACWP line where BAC = BCWP is the EAC.

REAC2 Cumulative CPI_p is regressed as a function of time. The final CPI_p is estimated and multiplied by the BAC to determine the EAC.

REAC3 The ACWP and BCWP are both regressed as a function of time. The time that corresponds to BCWP = BAC is imputed into the ACWP function in order to calculate the EAC.

(12:31)

Karsch Formula

$REAC4 = b_1 BAC^{b2}$

Calculate b_1 and b_2 with logarithm transformation using:

$ACWP = b_1 BCWP^{b2}$ (Unconstrained formula)

Constrained formula b^2 is held constant.

Log. transformation: $\ln ACWP = \ln b_1 + b_2 \ln BCWP$

(30:30-31)

SAMSO Formula

SAMSO REAC2 using only the current month and five previous months for least squares regression.

Bibliography

1. Automated Financial Analysis Program: A User's Guide. Cost Analysis Division Comptroller Electronic Systems Division Air Force Systems Division, Hanscom AFB, Bedford MA, May 1985.

2. Barnhart, Clarence L. and Barnhart, Robert K. The World Book Dictionary, Vol.2 L-Z. Chicago: World Book, Inc., 1984.

3. Beach, Chester Paul Jr., Inquiry Officer. Memorandum for the Secretary of the Navy, Subj.: A-12 Administrative Inquiry. Department of the Navy, Washington DC, 28 November 1990.

4. Betti, John A. "Keynote Speech to the Twenty-Fourth Annual DOD Cost Analysis Symposium," National Estimator: 3-6, Fall 1990.

5. Blythe, Col Ardven L. A Stochastic Model for Estimating Total Program Cost, ASD Reserve Report No. 84-135-TUL. Aeronautical Systems Division, Wright-Patterson AFB OH, undated.

6. -----. Validation of ASD/ACCM's Cost Performance Analysis Algorithm, ASD Reserve Project 82-135-TUL. Aeronautical Systems Division, Wright-Patterson AFB OH, December 1982.

7. Bright, Harold R. and Truman W. Howard, III. Weapon System Cost Control: Forecasting Contract Completion Costs, TR-FC-81-1. Comptroller/Cost Analysis Division, US Army Missile Command, Redstone Arsenal AL, September 1981.

8. Busse, Maj Daniel E. A Cost Performance Forecasting Model. MS Thesis. Air University, Maxwell Air Force Base AL, April 1977 (ADB019568).

9. Chacko, George K. "Improving Cost and Schedule Controls Through Adaptive Forecasting," Concepts: The Journal of Defense Systems Acquisition Management. Vol. 4, #1:73-96, Winter 1981.

10. Chase, Richard B. and Nicholas J. Aquilana. Production, and Operations Management: A Life Cycle Approach, (5th Edition.) Boston: Irwin, 1989.

11. Chatfield, Christopher. The Analysis of Time Series: An Introduction. London England: Chapman and Hall Ltd., 1984.

12. Covach, John, et Al. A Study to Determine Indicators and Methods to Compute Estimate at Completion (EAC). Mantech International Corporation: VI, June 1981.

13. Cryer, Maj James M. and Maj Leo R. Balthazor. Evaluation of Weighted Indices on Algorithms Utilized for Calculating Independent Estimates at Completion. ASD/HR MR Project No. 86-225, Wright-Patterson AFB OH, undated.

14. Defense Systems Management College, Contractor Performance Measurement, "Mod 6 Estimated Cost at Completion," Self Study Course. Defense Systems Management College, Fort Belvoir VA, February 1988.

15. Department of the Air Force. Acquisition Management. AFR 800-6 & Supplement 1. Washington DC: HQ USAF, 13 September 1985.

16. -----. Cost/Schedule Control Systems Criteria Joint Implementation Guide for DOD Instruction 7000.2, Performance Measurement for Selected Acquisitions. AFSCP 173-5. Washington DC: HQ AFSC, 1 October 1987.

17. -----. Cost/Schedule Control Systems Criteria, C/SCSC Joint Surveillance Guide. AFSCP 173-6. Washington DC: HQAFSC, 1 October 1984.

18. -----. Guide to Analysis of Contractor Cost Data. AFSCP 173-4. Washington DC: HQ AFSC, 1 September 1989.

19. Department of Defense Instruction. Defense Acquisition Management Policies and Procedures. DODI 5000.20. Washington DC: DOD, 23 Feb 1991.

20. El-Sabban, Zaki M. Forecast of Cost/Schedule Status Utilizing Cost Performance Reports of the Cost/Schedule Control Systems Criteria: A Bayesian Approach. U.S. Army Aviation Systems Command, St. Louis MO, January 1973 (AD754576).

21. Emory, William C. Business Research Methods. Homewood IL: Irwin, 1985.

22. Fleming, Quentin W. Cost/Schedule Control Systems Criteria: The Management Guide to C/SCSC. Chicago: Probus Publishing Company, undated.

23. Harnett, Donald L. Statistical Methods (3rd Edition). Reading MA: Addison-Wesley Publishing Co., 1982.

24. Haydon, Joseph J. and Riether, Richard O. Methods of Estimating Contract Cost at Completion. Mantech International Corporation: VI, January 1982.

25. Hayes, Capt Richard A. An Evaluation of a Bayesian Approach to Compute Estimates At Completion for Weapon System Programs. MS Thesis, AFIT/GSM/770-21. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September, 1977 (ADA056502).

26. Heydinger, Gerard N. Space and Missile Systems Organization Cost Performance Forecasting Study. Cost Analysis Division, Los Angeles CA, June 1977.

27. Holeman, Maj J.B. A Product Improved Method for Developing A Program Management Office Estimated Cost at Completion. Defense Systems Management School, Fort Belvoir VA, January 1975 (ADA007125).

28. Karsch, Arthur O. A Cost Performance Forecasting Concept and Model: Cost Research Report No. 117. Aeronautical System Division, Wright-Patterson AFB OH, November 1974.

29. ------. A Production Study Sequel to the Cost Performance Forecasting Concept and Model, Cost Research Report 132. Aeronautical Systems Division, Wright-Patterson AFB OH, August 1976.

30. Land, Capt Thomas J. and Capt Edward L. Preston. A Comparative Analysis of Two Cost Performance Forecasting Models: The Automated Financial Analysis Program, Electronic System Division, November 1976, Versus a Cost Performance Forecasting Concept and Model, Aeronautical Systems Division, November 1974. MS Thesis, LSSR 23-80. School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, June 1980 (ADA087500).

31. Levenbach, Hans and James P. Cleary. The Beginning Forecaster: The Forecasting Process Through Data Analysis. Belmont CA: Lifetime Learning Publications, 1981.

32. Lollar, 1st Lt James L. Cost Performance Analysis Program for Use on Hand-Held Programmable Calculators: User's Handbook. Aeronautical Systems Division, Wright-Patterson AFB OH, April 1980.

33. Markland, Robert E. Topics in Management Science (3rd Edition). New York: John Wiley & Sons, Inc., 1989.

34. Meredith, Jack R. and Samuel J. Mantel, Jr. Project Management: A Managerial Approach, (2nd Edition.) New York: John Wiley & Sons, Inc., 1989.

35. Morrison, David C. "Deep-Sixing the A-12," Government Executive: 30-35, March 1991.

36. Nauseef, Brig Gen "General Nauseef's Challenge," Performance Management Association: 24-26, Spring 1991.

37. Neter, John and others. Applied Lincan Regression Models (2nd Edition). Boston: Irwin, 1989.

38. Olsen, Capt David and Capt Roger W. Ellsworth. Forecasting Techniques Employed in a Line Organization: Cost Research Report 127. Aeronautical Systems Division, Wright-Patterson AFB OH, February 1976.

39. Payne, Maj Kirk I. An Investigation of the Stability of the Cost Performance Index. MS Thesis, AFIT/GCA/LSY/905-6. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1990 (ADA229498).

40. Price, Capt James B. An Evaluation of CPRA Estimate at Completion Techniques Based Upon AFWAL Cost/Schedule Control System Criteria Data. MS Thesis, AFIT/LSY/GSM/855-28. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1985 (ADA162282).

41. Reidel, Mark A. and Jamie L. Chance. Estimates at Completion (EAC): A Guide to Their Calculation and Application for Aircraft, Avionics, and Engine Programs. Aeronautical Systems Division, Wright-Patterson AFB OH, August 1989.

42. Scifers, Thomas, Inc. Performance Analyzer, User Manual. Tecolote Research, Inc., Manhatten Beach CA, July 1989.

43. Slemaker, Chuck M. The Principles and Practice of Cost/Schedule Control Systems. Princeton NJ: Petrocelli Books 1985.

44. Tiong, Robert L.K. "Effective Controls for Large Scale Construction Projects," Project Management Journal, Vol. 21, 1:32-42, March 1990.

45. Totaro, Capt Jeffrey A. "A Logical Approach to Estimate at Completion Formulas," Program Manager: Vol. 16, 6:29-33, November-December 1987.

46. Wallender, Capt Timothy J. HQ Air Force Systems Command Estimate at Completion Formula Justification. DCS/Comptroller, HQ Air Force Systems Command, Andrews AFB MD, February 1986.

47. Weida, Maj William J. A General Technique for R & D Cost Forecasting. USAFA-TR-77-12. US Air Force Academy CO, September 1977 (ADA046105).

Vita

John W. McKinney was born in Piqua, Ohio on April 25, 1948. He graduated from Miami East High School in Casstown, Ohio in 1966 and attended Miami and Wright State Universities in Ohio. In 1969 he joined the United States Air Force and served four years as a French Interpreter. Upon leaving the Air Force he attended The Ohio State University and graduated in 1975 with a Bachelor of Science in Animal Nutrition. The next ten years were spent working as a Medical Technologist in a private laboratory and hospital. During this time he returned to Wright State University and received another Bachelor of Science degree in Accounting in 1984. Upon graduation he started a new career at Wright-Patterson AFB in the Comptroller field. He worked on different programs as a Financial Specialist in the Budget and Cost areas. For three years he worked in the Cost/Schedule area doing C/S reviews of cost systems for his program, surveillance, participating in Industry to Industry C/S reviews (C/S flowdown), participated on other review teams, and analyzing CPR data for the Program Office. In May 1990 he entered the Air Force Institute of Technology majoring in Cost Analysis.

Permanent Address: 6810 Old Troy Pike
St. Paris, Ohio 43072

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1991	Master's Thesis

4. TITLE AND SUBTITLE
ESTIMATE-AT-COMPLETION RESEARCH -A REVIEW AND EVALUATION

5. FUNDING NUMBERS

6. AUTHOR(S)
John W. McKinney, GS-12, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GCA/LSY/91S-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This research derives from the Performance Measurement discipline and consists of a comprehensive analysis of Estimate-at-Completion (EAC) studies published since 1973. The EAC studies consisted of models, comparison studies, and computer analysis programs. The studies were located through the Defense Technical Information Center (DTIC), the Cost Library at Wright-Patterson Air Force Base OH, and professional periodicals or contracted research. Each study was categorized by formula type and described in terms of methodology and conclusions. Each study was evaluated based on clarity, documentation, methodology, and source. The description and evaluation of the studies are summarized in two tables. After reviewing the studies some areas were found to be weak. The AFSC formula that uses weighted percentages of .2 SPI and .8 CPI, is not supported by a critical review of the literature. In the area of comparison studies, different past performance factor formulas have been compared with respect to different percent completion points, type of contract, and type of product. A summary of the results are provided in Chapter II. Little work has been done comparing regression formulas to past performance factor formulas. Formal EAC theory was found to be rare.

14. SUBJECT TERMS
Estimate-at-Completion, Cost/Schedule Control System Criteria, Forecasting, Estimating

15. NUMBER OF PAGES
112

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL